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Pollution from Land Use Activities Reference Group

May 78

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S POLLUTION
E ACTIVITIES

INTERNATIONAL JOINT COMMISSION

LAND COVER ANALYSIS FOR THE UNITED STATES GREAT LAKES WATERSHEDS

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LAND COVER ANALYSIS
FOR THE UNITED STATES
GREAT LAKES WATERSHEDS

by

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To be used as a portion of the Technical Reports of the International Reference Group on GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES of the International Joint Commission--prepared in fulfillment of U.S. Environmental Protection Agency Contract No. 68-01-3850 with the Great Lakes Basin Commission.

May 1978

D I S C L A I M E R

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16. Abstract (Limit: 200 words)

An inventory of land use was compiled for the U.S. basin in 1973 and 1974 for PLUARG by the Laboratory for Applications of Remote Sensing (LARS), of Purdue University using LANDSAT I satellite data. This state-of-the-art pioneering work was done on a county basis with emphasis on urban, agriculture, and forest land uses.

By spring 1977 PLUARG needed refinement of that information. Technology for the utilization of LANDSAT satellite data had improved since the earlier efforts.

The information presented in this report was gathered to fill PLUARG's need for land cover analysis on a watershed basis. It was compiled using a more recent data base and a greatly advanced technology. The methodology used is described. Wherever possible, the information presented here should be used in lieu of that presented in the volumes entitled The Inventory of Land Use and Land Use Practices.

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INTRODUCTION

A critical element in the Pollution from Land Use Activities Reference Group Study for the International Joint Commission is an up-to-date inventory of land use. Such an inventory was compiled for the U.S. basin in 1973 and 1974 under Task B of PLUARG. The land use compilation was accomplished under contract with the United States Environmental Protection Agency by the Laboratory for Applications of Remote Sensing (LARS), of Purdue University using LANDSAT I satellite data. The LARS work was carried out on a county basis with emphasis on urban, agriculture, and forest land uses.

The LARS work was a state-of-the-art pioneering effort using satellite data on a large scale. While it offered a significant advancement in the technology, problems were left unsolved, particularly in defining urban areas. The results of this work are presented in the six-volume Inventory of Land Use and Land Use Practices, published by the International Joint Commission.

As the PLUARG study developed, new needs arose in the area of land use inventories. A particular need was a land use or land cover analysis by watershed. For the Overview Modeling effort in particular, a subwatershed land cover inventory was essential.

In the Spring of 1977 it was recognized that a land cover analysis by watershed was needed and that it was needed quickly. As the direction of the reference group developed so, too, did the technology for the utilization of LANDSAT satellite data. The computer technology and operator expertise had improved tremendously from the very first efforts made in the early 1970's. It was then decided by members of PLUARG Task B to seek good land cover estimates on a watershed basis. Based upon a proposal by the Great Lakes Basin Commission (GLBC), EPA contracted with the GLBC to identify major land cover classes by watersheds in the U.S. Great Lakes Basin. The Great Lakes Basin Commission awarded a subcontract to the General Electric Company of Beltsville, Maryland to carry out this new land cover analysis. They began work in the Fall of 1977 and completed their report in February of 1978 (see Appendix). Because of the improved technology, this work was accomplished in a five-month period with at lease nine classes of land cover being presented in each of 72 watersheds. The data were also updated to the 1976-1977 period.

The information presented herein is the result of this land cover analysis on a watershed basis. It must be recognized that this information was compiled using a more recent data base and a greatly advanced technology from that presented in the PLUARG Task B reports. Wherever possible, the information presented here should be used in lieu of that presented in the Task B reports entitled The Inventory of Land Use and Land Use Practices, (IJC, 1976).

METHODOLOGY

A detailed description of the methodology used by the General Electric Company is presented in the Appendix. The Appendix also includes a description of LANDSAT and the technology involved in utilizing satellite data.

Many land use inventories are accomplished by field sampling a certain subset which is representative of the area in question. This subset information is then extrapolated over the entire area. This is the case with the Conservation Needs Inventory (CNI), a much-used inventory of soil and water conservation needs within U.S. counties, published by the U.S. Soil Conservation Service. The 1967 CNI data is based on the sampling of two percent of the total area within a county. That information is then extrapolated to the remainder of the county. In the case of the Conservation Needs Inventory, the emphasis was placed on agriculture areas. The residential or urban area is the remaining unaccounted-for acreage once the cropland, forest, pasture, and non-inventoried areas have been designated. Other land inventory programs, at least on a micro scale, use the U.S. Census data or other local statistics to project population densities and areas affected by human activity.

Remote sensing data rely on electronics and computers to measure and analyze reflected light from every .45 hectares (1.1 acres) cell within the study area. This fingerprint of reflected light is then interpreted by a skilled photo-interpreter for the various classes. In the case of this study, every cell in the U.S. Great Lakes Basin has its own fingerprint and has been classified. Like the Conservation Needs Inventory, small training areas are selected that are representative of the entire data set. These training sets are analyzed and the results then applied to the entire data set. Unlike the Conservation Needs Inventory, every .45 hectare (1.1 acre) is sampled and thus can then be checked by the interpreter once the classification process has been complete. An adjustment of errors or reclassification can then be easily accomplished in a very short period of time. It must be realized that the end produce (the classified tables or computer tapes) must be used with the understanding that these data are a classification of remotely sensed information and are subject to further interpretation by the user.

Remote sensing data was utilized in this study due to the extremely rapid turnaround time available and the cost-effectiveness of such a study. This type of data base is very accurate for use on watershed and county scales. It would cost hundreds of thousands of dollars and take many months to compile such a land cover inventory using standard field procedures.

Data were chosen for the study from the Spring period primarily from 1976 and 1977. When using remote sensing it is advantageous to use various periods of the

same year to extract the maximum number of classifications. By using different data sets, it is possible to monitor the growth of crops, crop types, the changes in wetlands, and better classify cities and towns that are often covered by a tree canopy in the late spring and summer. Because of time and budget constraints, only one point in time was analyzed. The spring period allows the greatest separation of the classes that were of interest to this study. In the spring, there is no tree canopy to hide residential areas, and there is also a great separation between plowed fields and pasture. It does, however, yield a higher value for water areas and wetland areas, particularly if the spring had high amounts of precipitation.

When generating land cover tables by watershed using a computerized LANDSAT data base, there are inherent errors in matching the known total area of the watershed with the computerized total area of that same watershed. Areas presented by the Soil Conservation Service and in the Great Lakes Basin Framework Study (GLBC, 1974) for watersheds are based on the measurements of area within certain topographic lines. These area measurements have been used as a standard for many years. In the case of the computerized data base, the same topographic lines were used, but on maps of a different scale and using a different measurement technique. The computerized approach used by General Electric also includes the entire shoreline on the particular day and time that the satellite flew over, while the standard techniques define the shoreline as a certain topographic line along the shore. Together, these differences in methodology account for a zero to five percent difference between the computerized approach and the standard approach of measuring total land area. As a result, the General Electric figures for total land area for each of the watersheds vary somewhat from the areas adopted for the Great Lakes Basin Framework Study. In order to keep the total land cover data consistent with that used in past work, the variation of total land area within each of the watersheds was adjusted to the Great Lakes Basin Framework Study total drainage value. This was accomplished by multiplying the percentage of the various land classes found within a watershed by General Electric by the drainage area presented in the Great Lakes Basin Framework Study. The tables presented in the "Results" section of this report reflect the standard total land area found within the various watersheds. It should also be noted that the inland water area is over and above that of the total land area.

RESULTS

Tables 1 through 5 represent the tabulation of land cover for the entire U.S. Great Lakes drainage area. The name and a three-digit number correspond to each of the 72 hydrologic areas within the basin (see Hall, et al, 1976). The first digit of the number corresponds to the lake (1-Superior, 2-Michigan, 3-Huron, 4-Erie, 5-Ontario). The second digit is the river basin group number within the Lake basin. The third digit is the hydrologic area within the river basin group. Figures 1 through 15 show the river basin groups for the U.S. side and the hydrologic areas within those groups.

The land area is the total land area as obtained from the Great Lakes Basin Framework Study, Appendix 13, Land Use and Management (GLBC, 1974). This corresponds to all land area as well as water bodies of 40 acres or less in size. The total land area units are in square kilometers. The inland water class corresponds to water bodies greater than 40 acres and is over and above the land area. The units are in hectares and no percentage figure is given as it is above the total land area. The units for the remaining classes are hectares and percent of the total land area. The remaining classes are all defined with technical comments by General Electric in the Appendix, Section 4.

The following is a general overview of these classes based on experience with their use.

WETLAND

Because the data are from the spring period, wetland values may be high. Also, due to the two different years that were used in this data set, variations may occur in different regions. The class does rely on differences in vegetation as well as standing water to distinguish between a true wetland and a field that happens to be under water at the point in time the satellite flew over.

FOREST (DECIDUOUS AND CONIFEROUS)

The data for these classes appear to be very good, particularly in the northern portions of the basin. Wherever a good coniferous class could not be separated out, the deciduous class was defined as the total forest for the hydrologic area in question. Some problems did occur in eastern New York State, due to shadows formed by the sun. However, these problems were minimal.

BRUSHLAND

Brushland is generally a catch-all class that contains overgrown abandoned farms, newly-developing forests, low bush and brush, as well as developed areas

such as orchards or possibly vineyards. For these reasons brushland must be interpreted according to its geographical location.

GRASSLAND

The dominant land use incorporated in the grassland class is pastureland. It does include golf courses, large manicured lawns, as well as open fields of short grass. However, upon examining the class geographically, it is clearly dominated by the pastureland associated with the dairy industry.

BARREN

The barren class is also a catch-all definition which includes barren rock, sand beaches, small open pit mining operations, and other non-vegetated areas not associated with a city or agricultural activity.

PLOWED FIELD

The plowed field class represents a good data base throughout the basin. It includes farmland which is comprised of barren earth or recently plowed soil. Since the data are from the spring season, the maximum amount of plowed area would be anticipated. This class is significant in analyzing runoff from farmland that is frequently turned over or left barren.

HIGH DENSITY RESIDENTIAL

The data for this class are good around cities and suburban areas. It should be noted that it primarily defines high density residential signature and does not mean to portray a total residential figure. The classification also provides area around small towns (approximately 2,500 people or more). For low density areas such as those found in the Lake Superior basin, it is quite common to have no high density residential areas defined. This class is useful in that it displays the area where the majority of people live within the basin, and thus indicates the area where urban runoff and other urban related pollutants are likely to be concentrated.

COMMERCIAL AND INDUSTRIAL

This class is comprised of highly-developed areas with no vegetative cover associated with cities and are often discolored from industrial activities. The class represents only the highest density areas associated with large urban centers. It is a well defined class in that it does describe the core downtown area and impervious surfaces associated with the most significant structural development on the land.

Section 4.3 of the Appendix discusses the accuracy of the General Electric estimates. Also presented are a range of estimated accuracies. These values appear to be on the conservative side in that our evaluation of the data indicates that the data are more accurate than is indicated. The estimate of accuracy presented in the Appendix is standard for LANDSAT operations. It should be noted that the accuracy goes up as the user applies the definition of the classes or understands the general trend within a certain geographical area.

TABLE 1

LAKE SUPERIOR
HYDROLOGIC AREA SUMMARY

LAND COVER DATA - PART 1

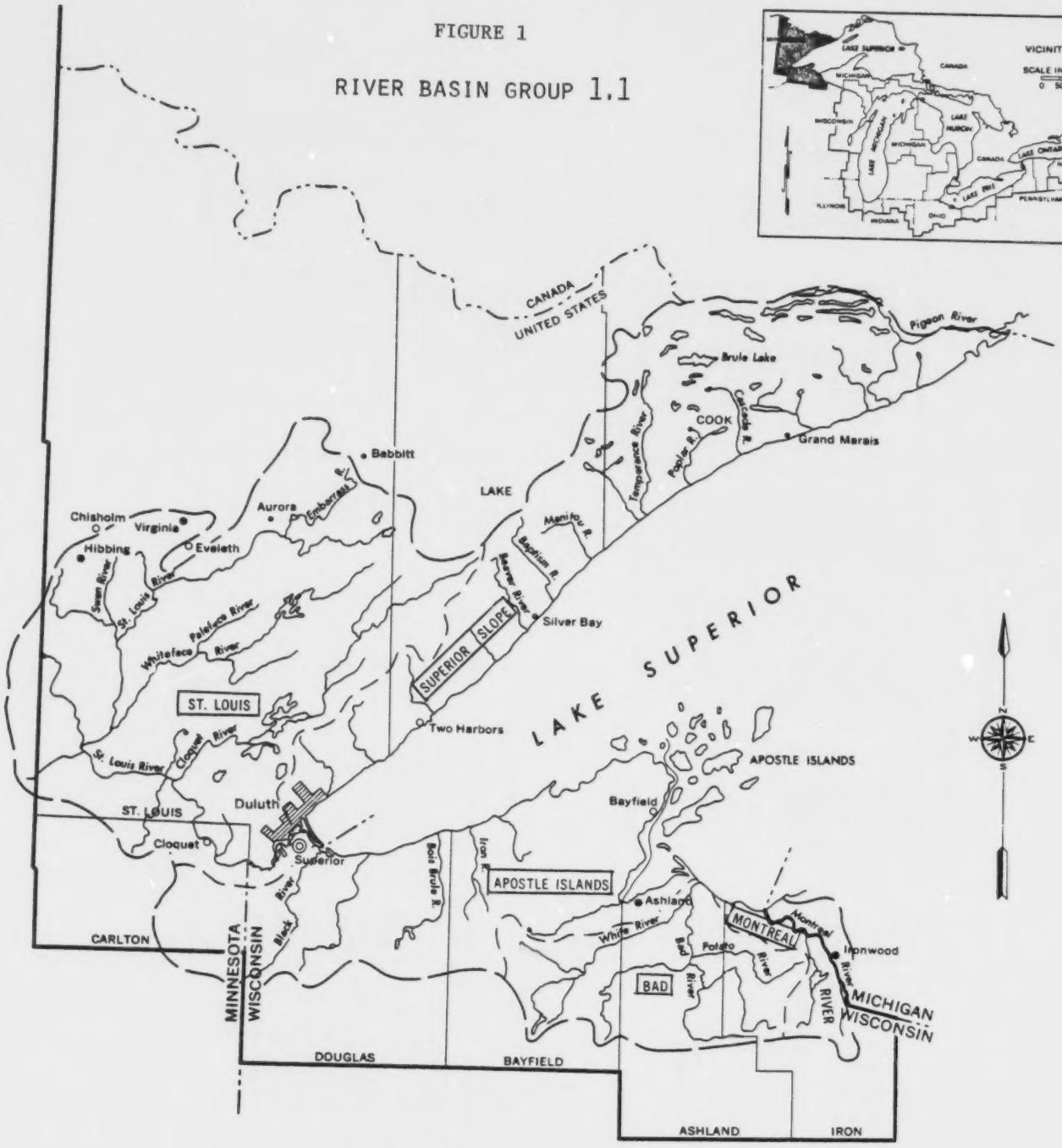
#	NAME	LAND AREA:KM2	INLAND WATER HA		WETLAND HA	%	FOREST (DECID) HA	%	FOREST (CON) HA	%	BRUSHLAND HA	%
111	SUPERIOR SL.	5950.	21420.		65425.	11.0	195659.	32.9	314782.	52.9	12962.	2.2
112	ST LOUIS	9440.	26432.		38848.	4.1	211720.	22.4	607967.	64.4	10683.	1.1
113	APOSTLE ISLE	5140.	3598.		8800.	1.7	305915.	59.5	114395.	22.3	48139.	9.4
114	BAD	2580.	3096.		13057.	5.1	123777.	48.0	80429.	31.2	28725.	11.1
115	MONTREAL COM	800.	1520.		7176.	9.0	29766.	37.2	31070.	38.8	9134.	11.4
121	PORCUPINE MT	2720.	4896.		24375.	9.0	117719.	43.3	118827.	43.7	8310.	3.1
122	ONTONOGAN	3530.	14473.		37913.	10.7	147237.	41.7	147973.	41.9	9938.	2.8
123	KEWEENAW COM	3500.	13300.		14189.	4.1	160447.	45.8	149168.	42.6	21102.	6.0
124	STURGEON	1830.	3111.		20664.	11.3	78189.	42.7	69439.	37.9	6888.	3.8
125	HURON MTS	2520.	5040.		11314.	4.5	115971.	46.0	104657.	41.5	13114.	5.2
126	GRAD MARAIS	3110.	10885.		9346.	3.0	188211.	60.5	93139.	29.9	11280.	3.6
127	TAHQUAMENON	2180.	1744.		11427.	5.2	101748.	46.7	102407.	47.0	1538.	0.7
128	SAULT COM	700.	1120.		7541.	10.8	17713.	25.3	25325.	36.2	10671.	15.2
TOTAL 13		44000.	110635.		270075.	6.1	1794069.	40.8	1959574.	44.5	192483.	4.4

LAND COVER DATA - PART 2

#	NAME	LAND AREA:KM2	GRASSLAND HA	%	BARREN HA	%	PLOWED FIELD HA	%	HIGH DENSITY RESIDENTIAL HA	%	COMMERCIAL HA	%
111	SUPERIOR SL.	5950.	1234.	0.2	1234.	0.2	3703.	0.6	0.	0.0	0.	0.0
112	ST LOUIS	9440.	43704.	4.6	26222.	2.8	0.	0.0	3885.	0.4	971.	0.1
113	APOSTLE ISLE	5140.	26916.	5.2	2070.	0.4	7247.	1.4	0.	0.0	518.	0.1
114	BAD	2580.	10445.	4.0	261.	0.1	1306.	0.5	0.	0.0	0.	0.0
115	MONTREAL COM	800.	2283.	2.9	82.	0.1	82.	0.1	408.	0.5	0.	0.0
121	PORCUPINE MT	2720.	1385.	0.5	831.	0.3	554.	0.2	0.	0.0	0.	0.0
122	ONTONOGAN	3530.	2945.	0.8	368.	0.1	6626.	1.9	0.	0.0	0.	0.0
123	KEWEENAW COM	3500.	0.	0.0	1819.	0.5	2183.	0.6	1091.	0.3	0.	0.0
124	STURGEON	1830.	5585.	3.1	372.	0.2	1862.	1.0	0.	0.0	0.	0.0
125	HURON MTS	2520.	4629.	1.8	514.	0.2	514.	0.2	1286.	0.5	0.	0.0
126	GRAD MARAIS	3110.	7412.	2.4	1289.	0.4	0.	0.0	322.	0.1	0.	0.0
127	TAHQUAMENON	2180.	659.	0.3	220.	0.1	0.	0.0	0.	0.0	0.	0.0
128	SAULT COM	700.	7327.	10.5	71.	0.1	1209.	1.7	142.	0.2	0.	0.0
TOTAL 13		44000.	114525.	2.6	35355.	0.8	25285.	0.6	7134.	0.2	1489.	0.0

FIGURE 1

RIVER BASIN GROUP 1.1



SCALE IN MILES

0 5 10 15 20 25

FIGURE 2

RIVER BASIN GROUP 1.2

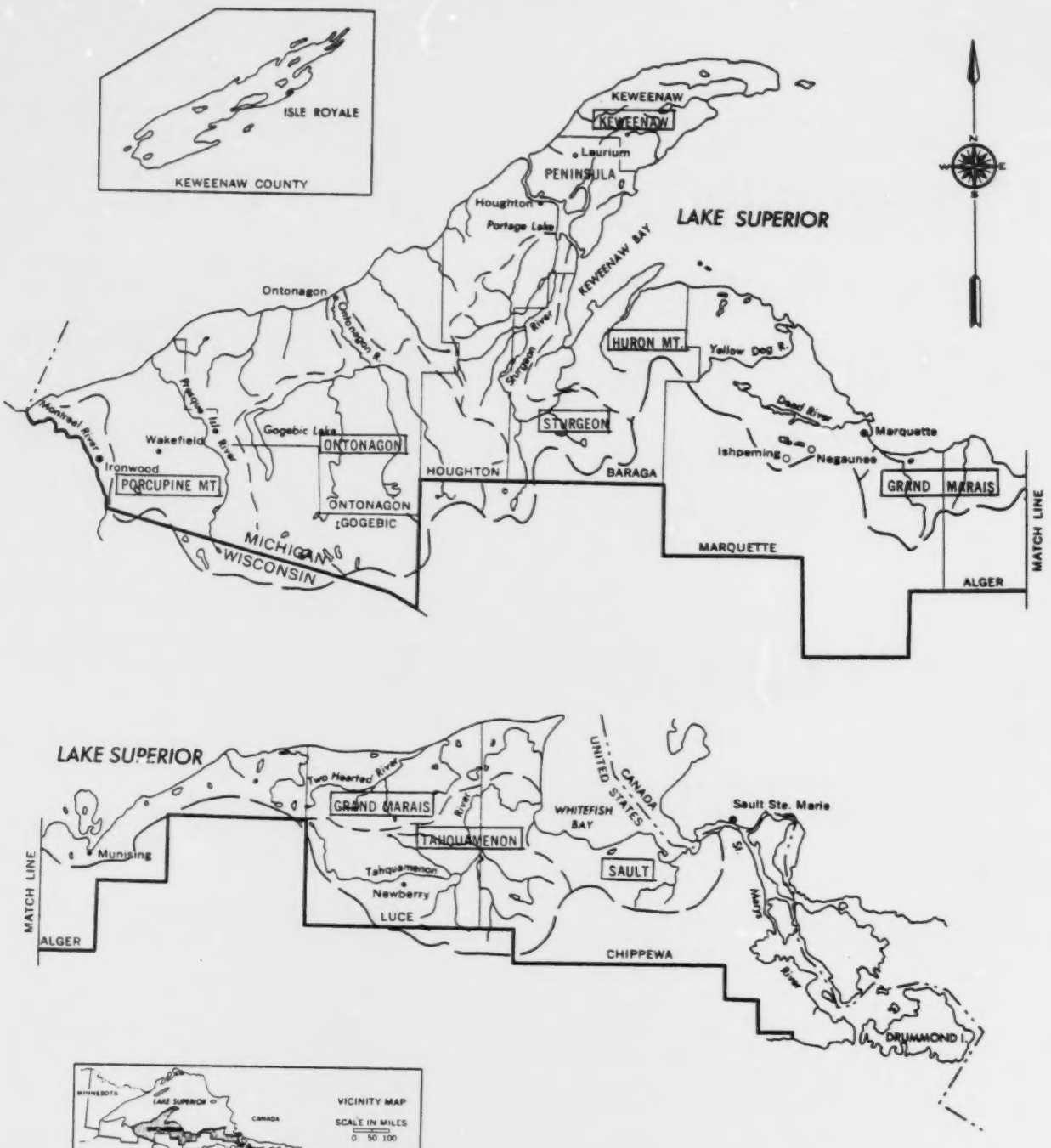


TABLE 2

LAKE MICHIGAN
HYDROLOGIC AREA SUMMARY

LAND COVER DATA - PART 1

#	NAME	LAND AREA:KM2	INLAND WATER HA	WETLAND HA	WETLAND %	FOREST (DECID) HA	FOREST (DECID) %	FOREST (CON) HA	FOREST (CON) %	BRUSHLAND HA	BRUSHLAND %
211	MENOMINEE CO	2730.	819.	5203.	1.9	121577.	44.5	105147.	38.5	31489.	11.5
212	MENOMINEE R	10610.	29708.	157185.	14.8	470464.	44.3	348209.	32.8	53487.	5.0
213	PESHTIGO	2980.	5662.	26732.	9.0	145203.	48.7	82322.	27.6	19138.	6.4
214	OCONTO	2750.	4400.	14533.	5.3	135823.	49.4	69309.	25.2	20401.	7.4
215	SUAMICO COM	1250.	750.	8174.	6.5	50050.	40.0	13833.	11.1	17480.	14.0
216	FOX	17100.	99180.	65350.	3.8	629904.	36.8	190605.	11.1	321305.	18.8
217	GREEN BAY CO	6250.	6875.	20222.	3.2	177578.	28.4	59403.	9.5	121967.	19.5
221	CHICAGO-MILW	5630.	5630.	13648.	2.4	153545.	27.3	0.	0.0	69948.	12.4
231	ST JOSEPH	12110.	19376.	50458.	4.2	157528.	13.0	50458.	4.2	301519.	24.9
232	BLACK SH COM	930.	930.	3570.	3.8	17755.	19.1	17379.	18.7	33442.	36.0
233	KALAMAZOO	5200.	8840.	20631.	4.0	101567.	19.5	22218.	4.3	152350.	29.3
234	BLACK R OTTA	660.	2244.	10658.	16.1	15851.	24.0	0.	0.0	18516.	28.1
235	GRAND	14660.	11728.	57635.	3.9	376845.	25.7	0.	0.0	302953.	20.7
241	MUSKEGON	6850.	24660.	48320.	7.1	324735.	47.4	95218.	13.9	132879.	19.4
242	SABLE COM	5030.	8048.	66964.	13.3	264279.	52.5	0.	0.0	102236.	20.3
243	MANISTEE	5200.	5200.	21535.	4.1	192242.	37.0	139717.	26.9	119758.	23.0
244	TRAVERSE COM	6830.	47127.	19074.	2.8	291247.	42.6	120314.	17.6	158462.	23.2
245	SEUL-CHOIX C	1420.	6106.	3858.	2.7	72558.	51.1	60094.	42.3	2077.	1.5
246	*MANISTIQUE	3750.	16500.	11768.	3.1	208290.	55.5	127877.	34.1	2746.	0.7
247	BAY DE NOC C	3100.	2170.	13112.	4.2	129245.	41.7	126123.	40.7	31843.	10.3
248	ESCANABA	2370.	3318.	9855.	4.2	80042.	33.8	98309.	41.5	43025.	18.2
TOTAL	21	117410.	309271.	648485.	5.5	4116320.	35.1	1726532.	14.7	2057014.	17.5

LAND COVER DATA - PART 2

#	NAME	LAND AREA:KM2	GRASSLAND HA	GRASSLAND %	BARREN HA	BARREN %	PLOWED FIELD HA	PLOWED FIELD %	HIGH DENSITY RESIDENTIAL HA	HIGH DENSITY RESIDENTIAL %	COMMERCIAL HA	COMMERCIAL %
211	MENOMINEE CO	2730.	7667.	2.8	274.	0.1	274.	0.1	1369.	0.5	0.	0.0
212	MENOMINEE R	10610.	16373.	1.5	1092.	0.1	14190.	1.3	0.	0.0	0.	0.0
213	PESHTIGO	2980.	13366.	4.5	0.	0.0	11240.	3.8	0.	0.0	0.	0.0
214	OCONTO	2750.	24035.	8.7	0.	0.0	10899.	4.0	0.	0.0	0.	0.0
215	SUAMICO COM	1250.	24145.	19.3	0.	0.0	8803.	7.0	2264.	1.8	252.	0.2
216	FOX	17100.	314044.	18.4	0.	0.0	156115.	9.1	29045.	1.7	3631.	0.2
217	GREEN BAY CO	6250.	139661.	22.3	632.	0.1	94793.	15.2	10743.	1.7	0.	0.0
221	CHICAGO-MILW	5630.	118287.	21.0	2275.	0.4	63124.	11.2	127386.	22.6	14786.	2.6
231	ST JOSEPH	12110.	152606.	12.6	1231.	0.1	450433.	37.2	44305.	3.7	2461.	0.2
232	BLACK SH COM	930.	6576.	7.1	94.	0.1	13433.	14.4	752.	0.8	0.	0.0
233	KALAMAZOO	5200.	69298.	13.3	529.	0.1	120081.	23.1	31740.	6.1	1587.	0.3
234	BLACK R OTTA	660.	5466.	8.3	68.	0.1	8335.	12.6	6832.	10.4	273.	0.4
235	GRAND	14660.	263052.	17.9	1478.	0.1	372411.	25.4	87192.	5.9	4433.	0.3
241	MUSKEGON	6850.	27713.	4.0	711.	0.1	36240.	5.3	18475.	2.7	711.	0.1
242	SABLE COM	5030.	29137.	5.8	1022.	0.2	25048.	5.0	14313.	2.8	0.	0.0
243	MANISTEE	5200.	19434.	3.7	525.	0.1	25737.	4.9	1051.	0.2	0.	0.0
244	TRAVERSE COM	6830.	48419.	7.1	1467.	0.2	42550.	6.2	1467.	0.2	0.	0.0
245	SEUL-CHOIX C	1420.	1632.	1.1	1335.	0.9	0.	0.0	445.	0.3	0.	0.0
246	*MANISTIQUE	3750.	1961.	0.5	21967.	5.9	0.	0.0	392.	0.1	0.	0.0
247	BAY DE NOC C	3100.	8429.	2.7	312.	0.1	0.	0.0	937.	0.3	0.	0.0
248	ESCANABA	2370.	4327.	1.8	721.	0.3	0.	0.0	721.	0.3	0.	0.0
TOTAL	21	117410.	1295624.	11.0	35732.	0.3	1453703.	12.4	379427.	3.2	28134.	0.2

FIGURE 3

RIVER BASIN GROUP 2.1

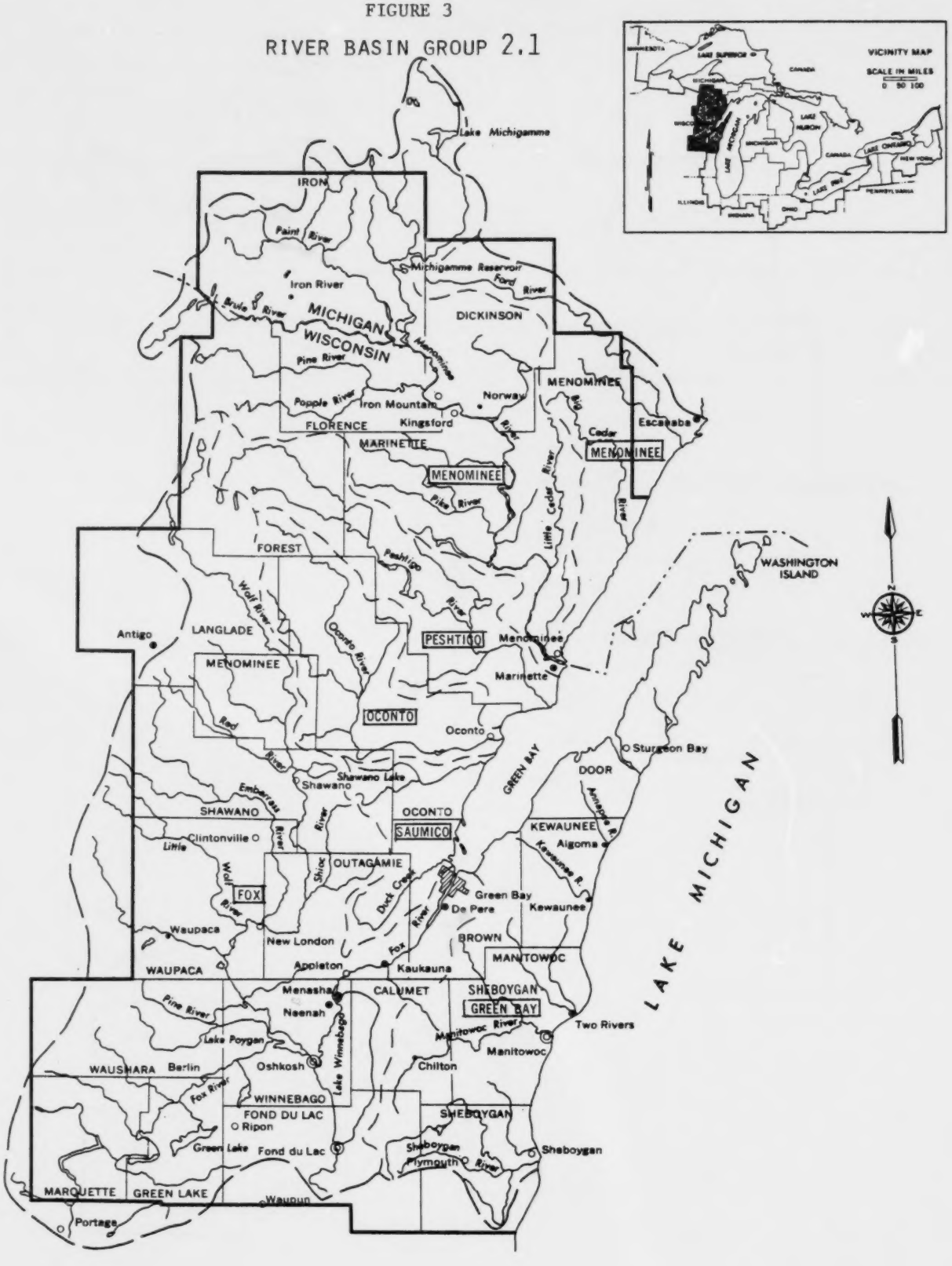


FIGURE 4

RIVER BASIN GROUP 2.2

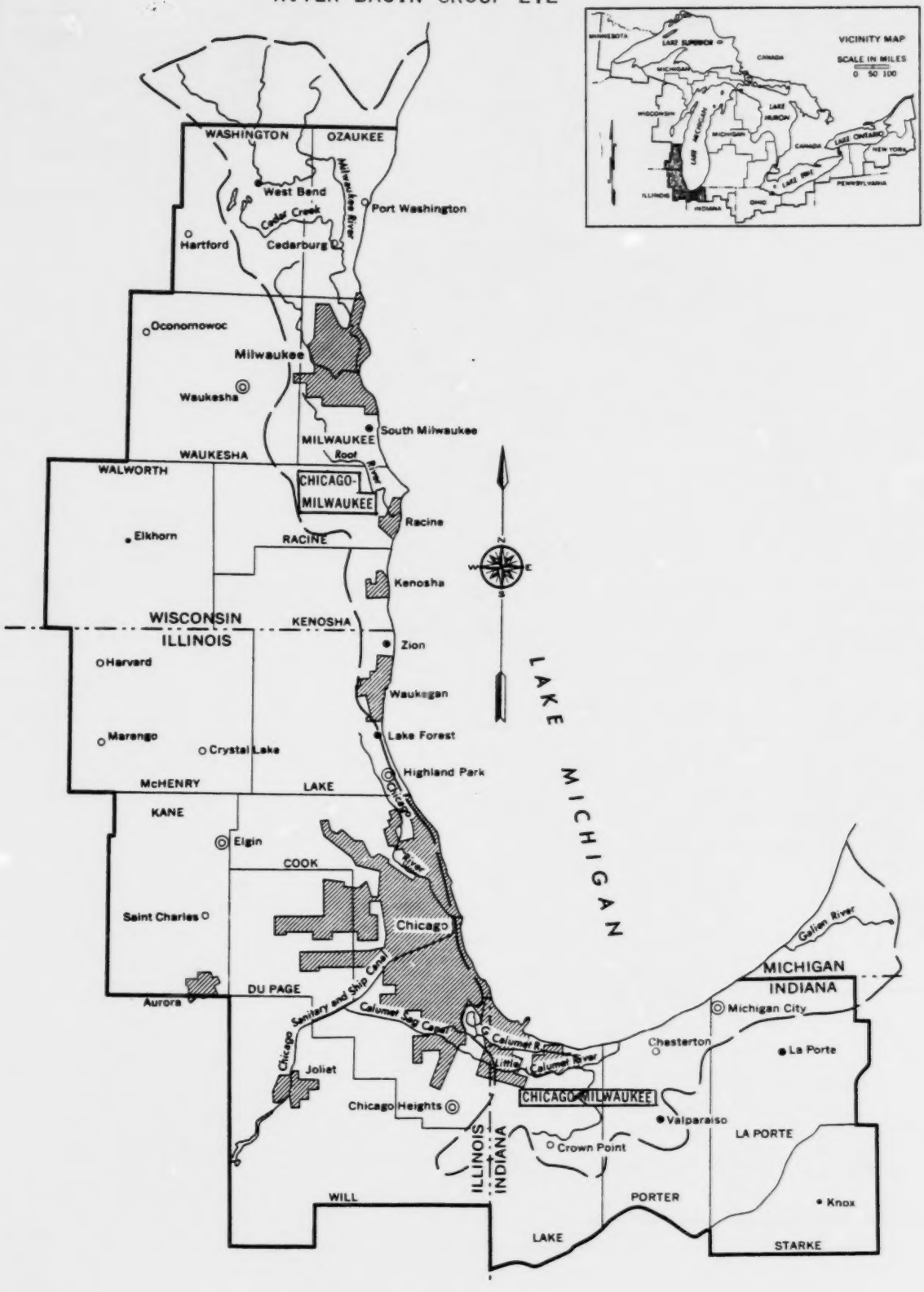
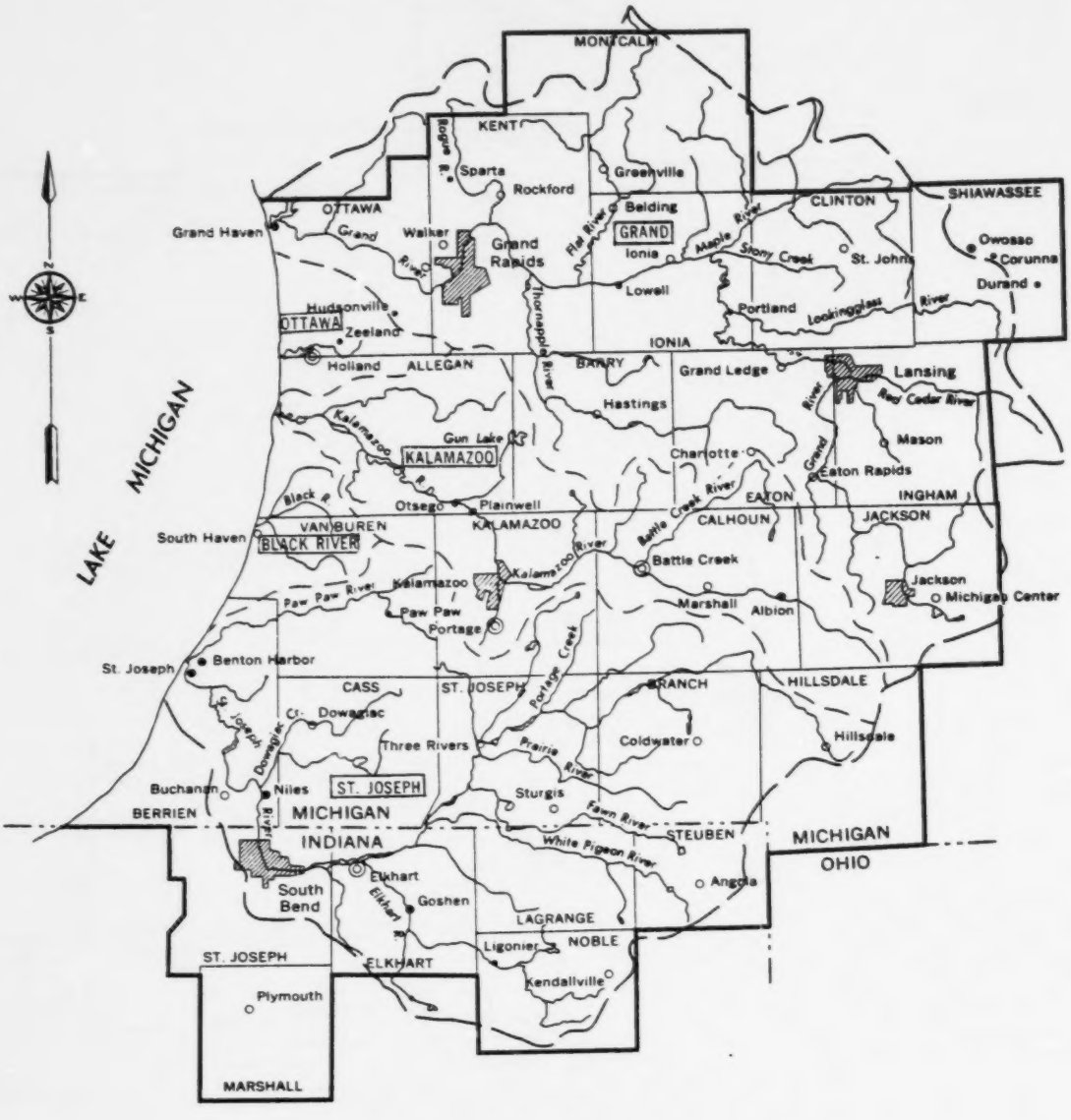
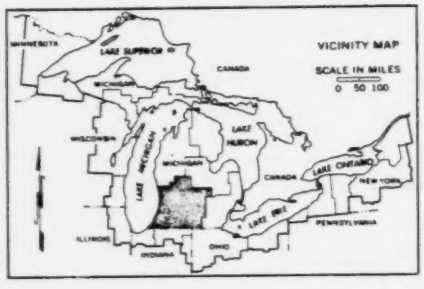


FIGURE 5

RIVER BASIN GROUP 2.3





SCALE IN MILES

0 5 10 15 20 25

FIGURE 6

RIVER BASIN GROUP 2.4

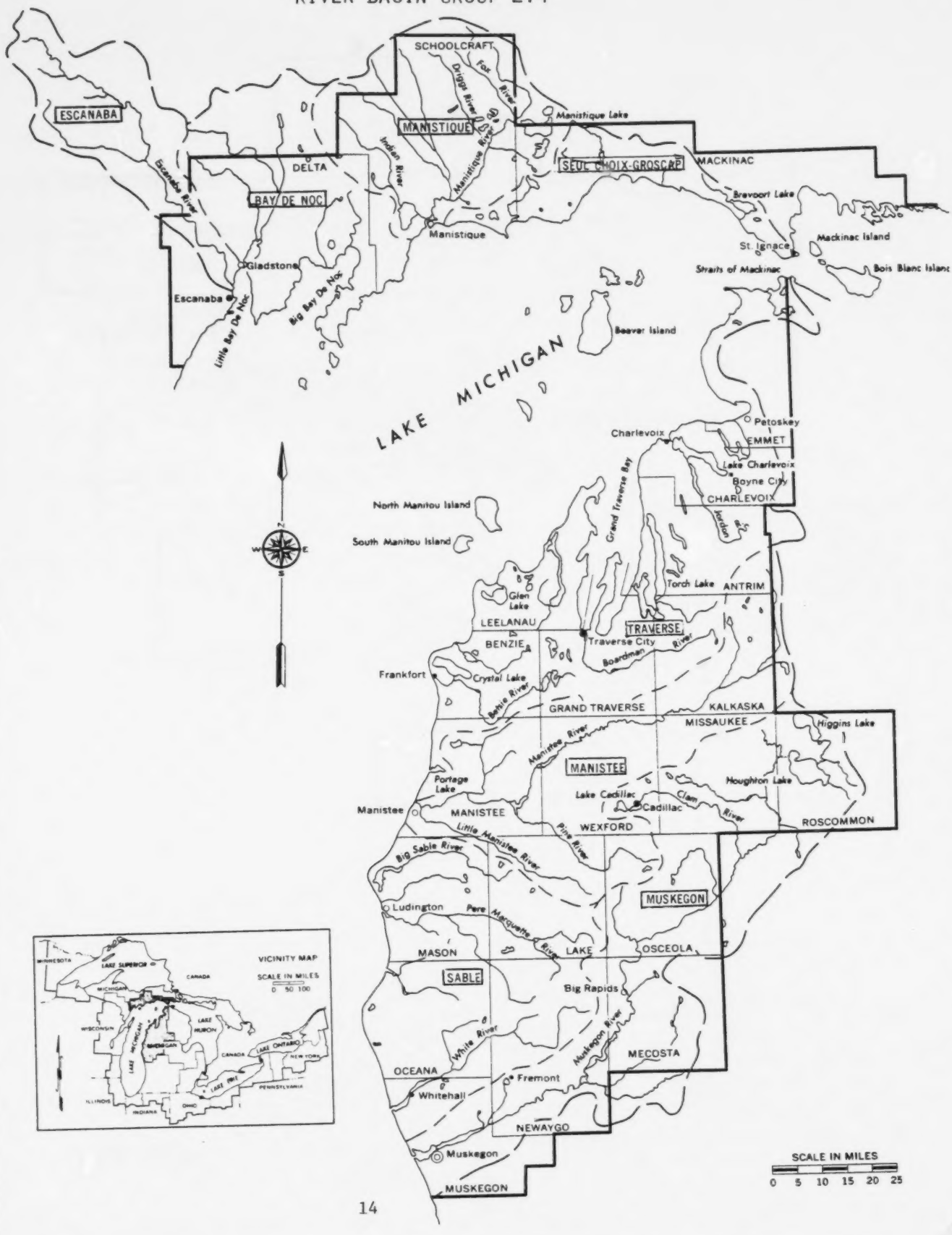


TABLE 3

LAKE HURON
HYDROLOGIC AREA SUMMARY

LAND COVER DATA - PART 1

#	NAME	LAND AREA:KM2	INLAND WATER HA	WETLAND HA	WETLAND %	FOREST (DECID) HA	FOREST (DECID) %	FOREST (CON) HA	FOREST (CON) %	BRUSHLAND HA	BRUSHLAND %
311	LES CHENEAUX	3640.	32032.	43105.	11.8	62263.	17.1	177211.	48.7	39912.	11.0
312	CHEBOYGAN	4090.	23313.	18650.	4.6	149634.	36.6	127081.	31.1	61155.	15.0
313	PRESQUE ISLE	1450.	5655.	6337.	4.4	26556.	18.3	70161.	48.4	20671.	14.3
314	THUNDER BAY	3270.	8829.	2016.	0.6	93092.	28.5	109560.	33.5	84018.	25.7
315	AU SABLE-ALC	5760.	8640.	51460.	8.9	153210.	26.6	262562.	45.6	82453.	14.3
316	RIFLE-AUGRES	2870.	3444.	2614.	0.9	78431.	27.3	69136.	24.1	89760.	31.3
321	KAWKAWLIN CO	1000.	100.	1001.	1.0	28729.	28.7	0.	0.0	18719.	18.7
322	SAGINAW	16170.	11319.	29311.	1.8	530858.	32.8	37453.	2.3	322423.	19.9
323	THUMB COM	3670.	5872.	7086.	1.9	50351.	13.7	746.	0.2	55572.	15.1
TOTAL 9		41920.	99204.	161582.	3.9	1173123.	28.0	853909.	20.4	774683.	18.5

LAND COVER DATA - PART 2

#	NAME	LAND AREA:KM2	GRASSLAND HA	GRASSLAND %	BARREN HA	BARREN %	PLOWED FIELD HA	PLOWED FIELD %	HIGH DENSITY RESIDENTIAL HA	HIGH DENSITY RESIDENTIAL %	COMMERCIAL HA	COMMERCIAL %
311	LES CHENEAUX	3640.	34724.	9.5	798.	0.2	5588.	1.5	399.	0.1	0.	0.0
312	CHEBOYGAN	4090.	45107.	11.0	434.	0.1	6506.	1.6	434.	0.1	0.	0.0
313	PRESQUE ISLE	1450.	12976.	8.9	1056.	0.7	6488.	4.5	754.	0.5	0.	0.0
314	THUNDER BAY	3270.	21845.	6.7	336.	0.1	15123.	4.6	1008.	0.3	0.	0.0
315	AU SABLE-ALC	5760.	11111.	1.9	585.	0.1	12865.	2.2	1754.	0.3	0.	0.0
316	RIFLE-AUGRES	2870.	19463.	6.8	871.	0.3	25853.	9.0	871.	0.3	0.	0.0
321	KAWKAWLIN CO	1000.	10110.	10.1	0.	0.0	33634.	33.6	7708.	7.7	100.	0.1
322	SAGINAW	16170.	184009.	11.4	1628.	0.1	400586.	24.8	105846.	6.5	4885.	0.3
323	THUMB COM	3670.	47740.	13.0	373.	0.1	183500.	50.0	21632.	5.9	0.	0.0
TOTAL 9		41920.	387084.	9.2	6082.	0.1	690143.	16.5	140407.	3.3	4985.	0.1

FIGURE 7

RIVER BASIN GROUP 3.1

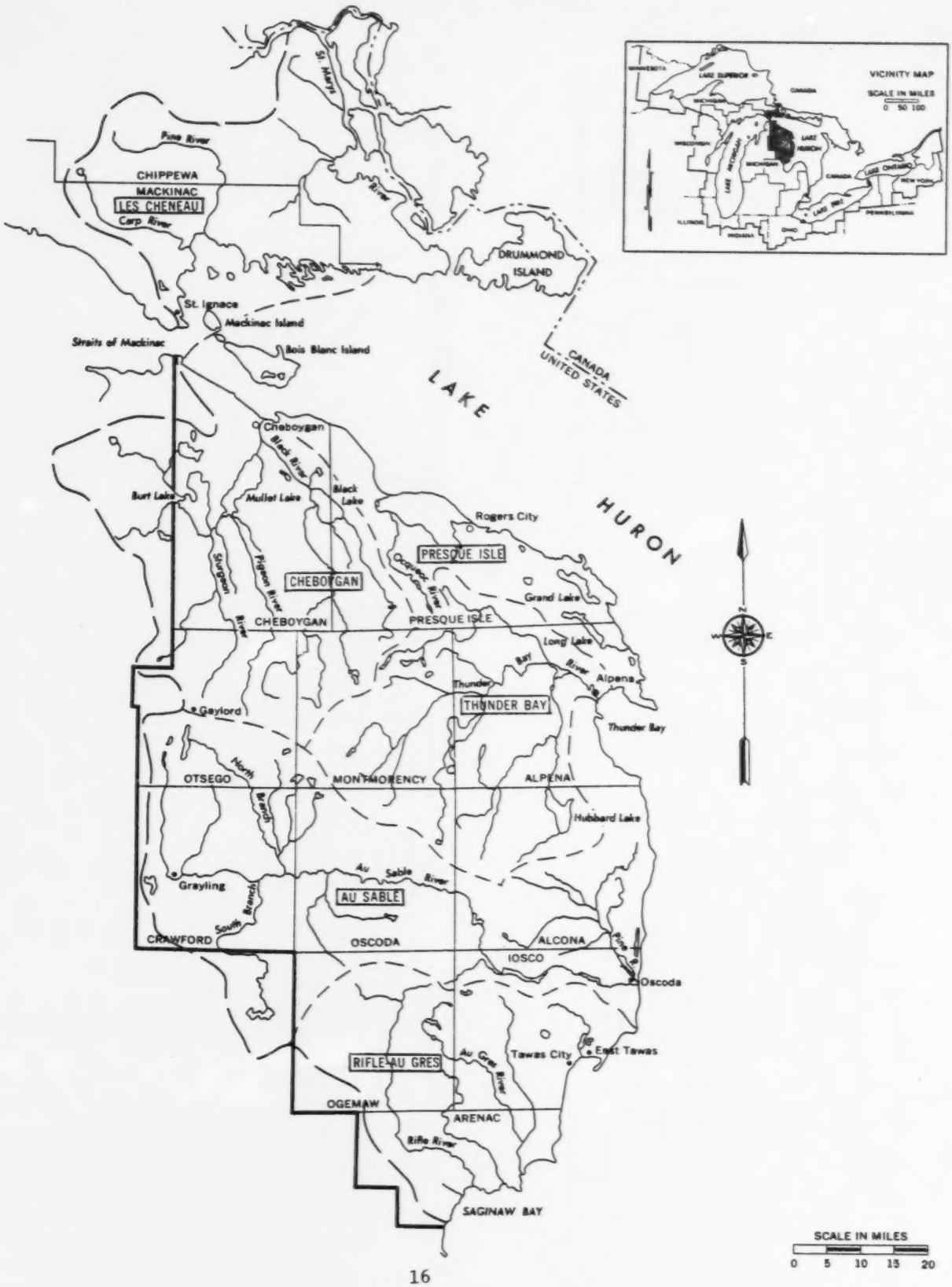
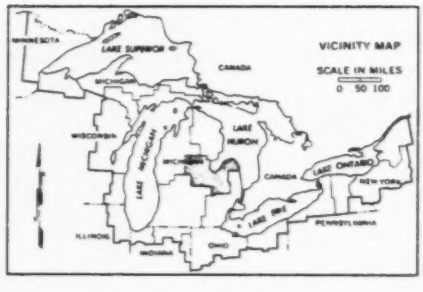


FIGURE 8

RIVER BASIN GROUP 3.2



SCALE IN MILES

0 5 10 15 20

TABLE 4

LAKE ERIE
HYDROLOGIC AREA SUMMARY

LAND COVER DATA - PART 1

#	NAME	LAND AREA!KM2	INLAND WATER HA		WETLAND HA	%	FOREST (DECID) HA	%	FOREST (CON) HA	%	BRUSHLAND HA	%
411	BLACK MI	1800.	900.		7236.	4.0	29668.	16.5	0.	0.0	37266.	20.7
412	ST CLAIR COM	1550.	1240.		5625.	3.6	32812.	21.2	0.	0.0	40312.	26.0
413	CLINTON	2030.	4872.		4160.	2.0	53246.	26.2	0.	0.0	41182.	20.3
414	ROUGE COM	1890.	1134.		570.	0.3	19775.	10.5	0.	0.0	34796.	18.4
415	HURON MI	2200.	7040.		5227.	2.4	60227.	27.4	0.	0.0	68636.	31.2
416	SWAN CR COM	740.	74.		1037.	1.4	8815.	11.9	0.	0.0	20444.	27.6
417	RAISIN COM	3260.	2608.		3944.	1.2	34835.	10.7	0.	0.0	67369.	20.7
421	OTTAWA	440.	220.		221.	0.5	3715.	8.4	0.	0.0	9994.	22.7
422	MAUMEE	17110.	8555.		10318.	0.6	98017.	5.7	0.	0.0	314686.	18.4
423	TOUSSAINT-PC	2660.	2660.		2956.	1.1	19345.	7.3	0.	0.0	47289.	17.8
424	SANDUSKY	3970.	794.		2785.	0.7	47735.	12.0	0.	0.0	54896.	13.8
425	HURON-VERM C	2670.	2670.		7552.	2.8	26970.	10.1	0.	0.0	58255.	21.8
431	BLACK-ROCKYC	2300.	460.		3457.	1.5	40331.	17.5	0.	0.0	51162.	22.2
432	CUYAHOGA	2340.	2106.		6612.	2.8	65171.	27.9	0.	0.0	26918.	11.5
433	CHAGRIN COM	770.	77.		1079.	1.4	24973.	32.4	0.	0.0	3854.	5.0
434	GRAND OH	2120.	212.		5093.	2.4	56236.	26.5	0.	0.0	42442.	20.0
435	ASHTABULA-CC	900.	0.		810.	0.9	23760.	26.4	0.	0.0	10530.	11.7
441	ERIE-CHAUT C	1690.	507.		678.	0.4	44072.	26.1	6272.	3.7	25935.	15.3
442	CATTARAUGUS	1440.	432.		867.	0.6	71061.	49.3	10832.	7.5	16899.	11.7
443	TONAWANDA CO	3710.	742.		1487.	0.4	181039.	48.8	46840.	12.6	46840.	12.6
TOTAL 20		55590.	37303.		71712.	1.3	941803.	16.9	63944.	1.2	1019706.	18.3

LAND COVER DATA - PART 2

#	NAME	LAND AREA!KM2	GRASSLAND HA	%	BARREN HA	%	PLOWED FIELD HA	%	HIGH DENSITY RESIDENTIAL HA	%	COMMERCIAL HA	%
411	BLACK MI	1800.	26412.	14.7	362.	0.2	65668.	36.5	12663.	7.0	724.	0.4
412	ST CLAIR COM	1550.	21875.	14.1	156.	0.1	35937.	23.2	18125.	11.7	156.	0.1
413	CLINTON	2030.	16431.	8.1	624.	0.3	32447.	16.0	48462.	23.9	6448.	3.2
414	ROUGE COM	1890.	7606.	4.0	190.	0.1	12359.	6.5	79479.	42.1	34225.	18.1
415	HURON MI	2200.	21136.	9.6	227.	0.1	37500.	17.0	25000.	11.4	2045.	0.9
416	SWAN CR COM	740.	3630.	4.9	74.	0.1	27037.	36.5	12889.	17.4	74.	0.1
417	RAISIN COM	3260.	36478.	11.2	329.	0.1	155442.	47.7	26290.	8.1	1315.	0.4
421	OTTAWA	440.	2830.	6.4	44.	0.1	17777.	40.4	6987.	15.9	2432.	5.5
422	MAUMEE	17110.	214950.	12.6	1720.	0.1	971573.	56.8	94578.	5.5	5159.	0.3
423	TOUSSAINT-PC	2660.	13434.	5.1	537.	0.2	152883.	57.5	28749.	10.8	806.	0.3
424	SANDUSKY	3970.	47338.	11.9	2785.	0.7	219981.	55.4	21083.	5.3	398.	0.1
425	HURON-VERM C	2670.	56367.	21.1	539.	0.2	96012.	36.0	20497.	7.7	809.	0.3
431	BLACK-ROCKYC	2300.	80661.	35.1	0.	0.0	29038.	12.6	24429.	10.6	922.	0.4
432	CUYAHOGA	2340.	75560.	32.3	0.	0.0	7084.	3.0	44155.	18.9	8501.	3.6
433	CHAGRIN COM	770.	29521.	38.3	0.	0.0	1002.	1.3	12949.	16.8	3623.	4.7
434	GRAND OH	2120.	85734.	40.4	0.	0.0	7427.	3.5	14643.	6.9	424.	0.2
435	ASHTABULA-CC	900.	33300.	37.0	4410.	4.9	1620.	1.8	13770.	15.3	1800.	2.0
441	ERIE-CHAUT C	1690.	37800.	22.4	11018.	6.5	5594.	3.3	30512.	18.1	7119.	4.2
442	CATTARAUGUS	1440.	28887.	20.1	0.	0.0	13432.	9.3	1878.	1.3	144.	0.1
443	TONAWANDA CO	3710.	42379.	11.4	372.	0.1	33457.	9.0	15985.	4.3	2602.	0.7
TOTAL 20		55590.	882327.	15.9	23387.	0.4	1923264.	34.6	553122.	10.0	79726.	1.4

FIGURE 9

RIVER BASIN GROUP 4.1

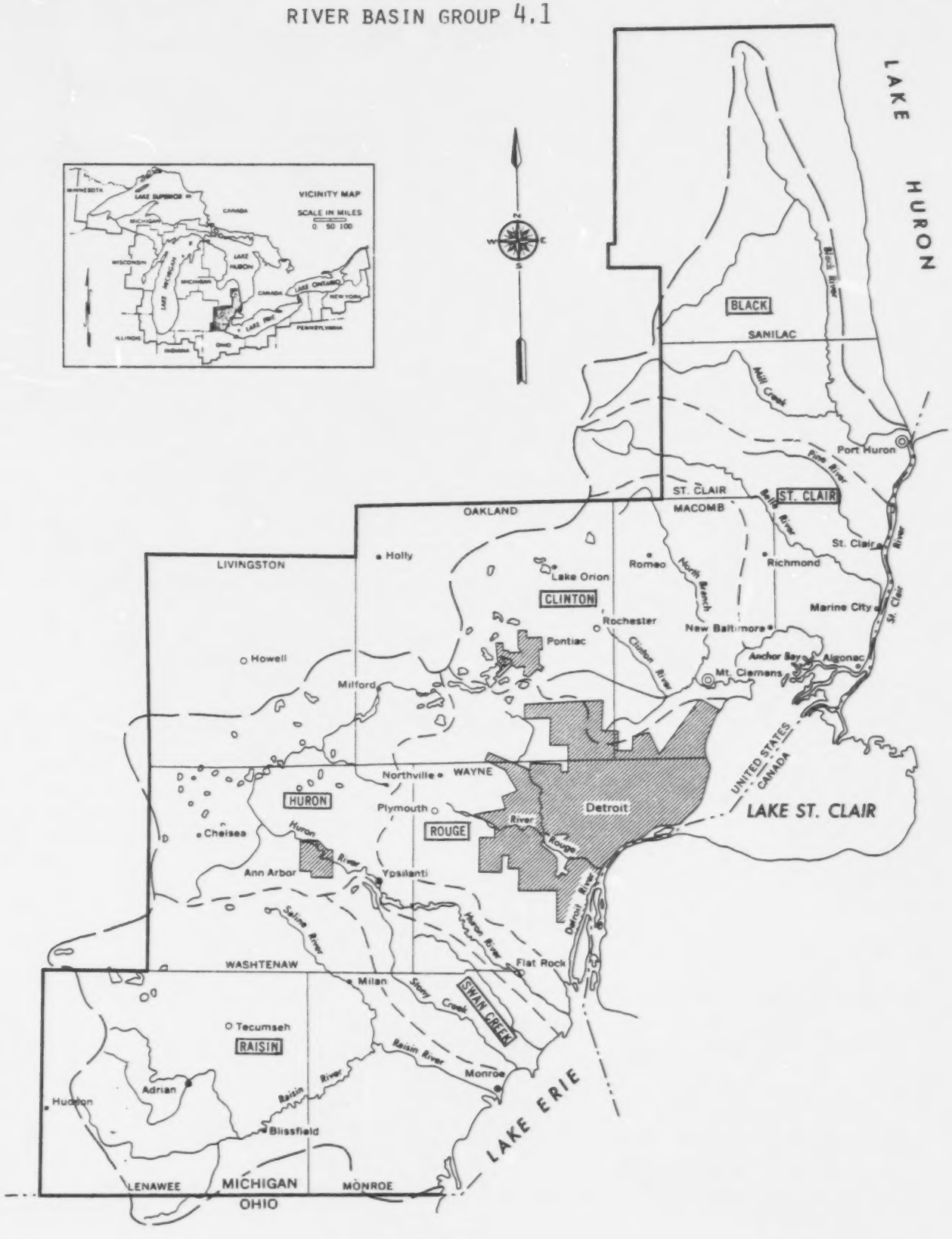
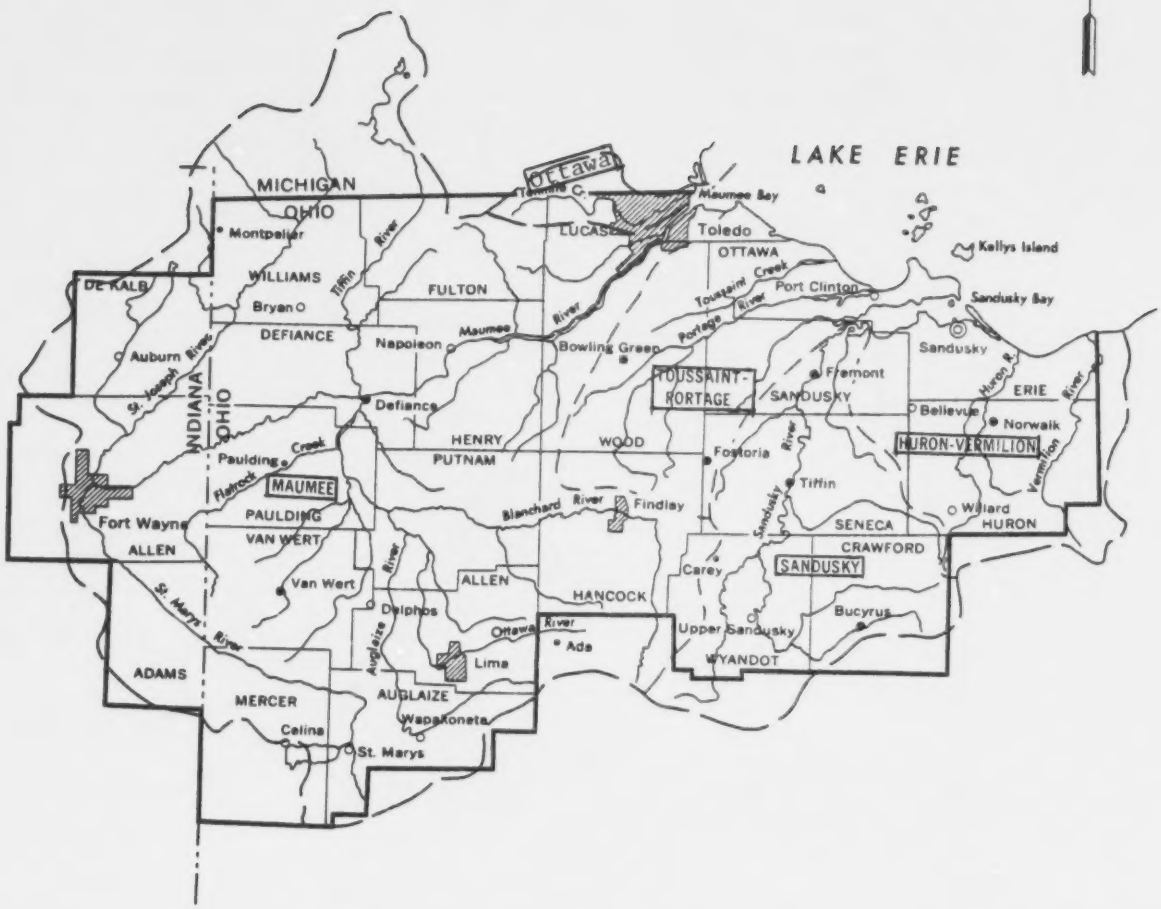


FIGURE 10

RIVER BASIN GROUP 4.2

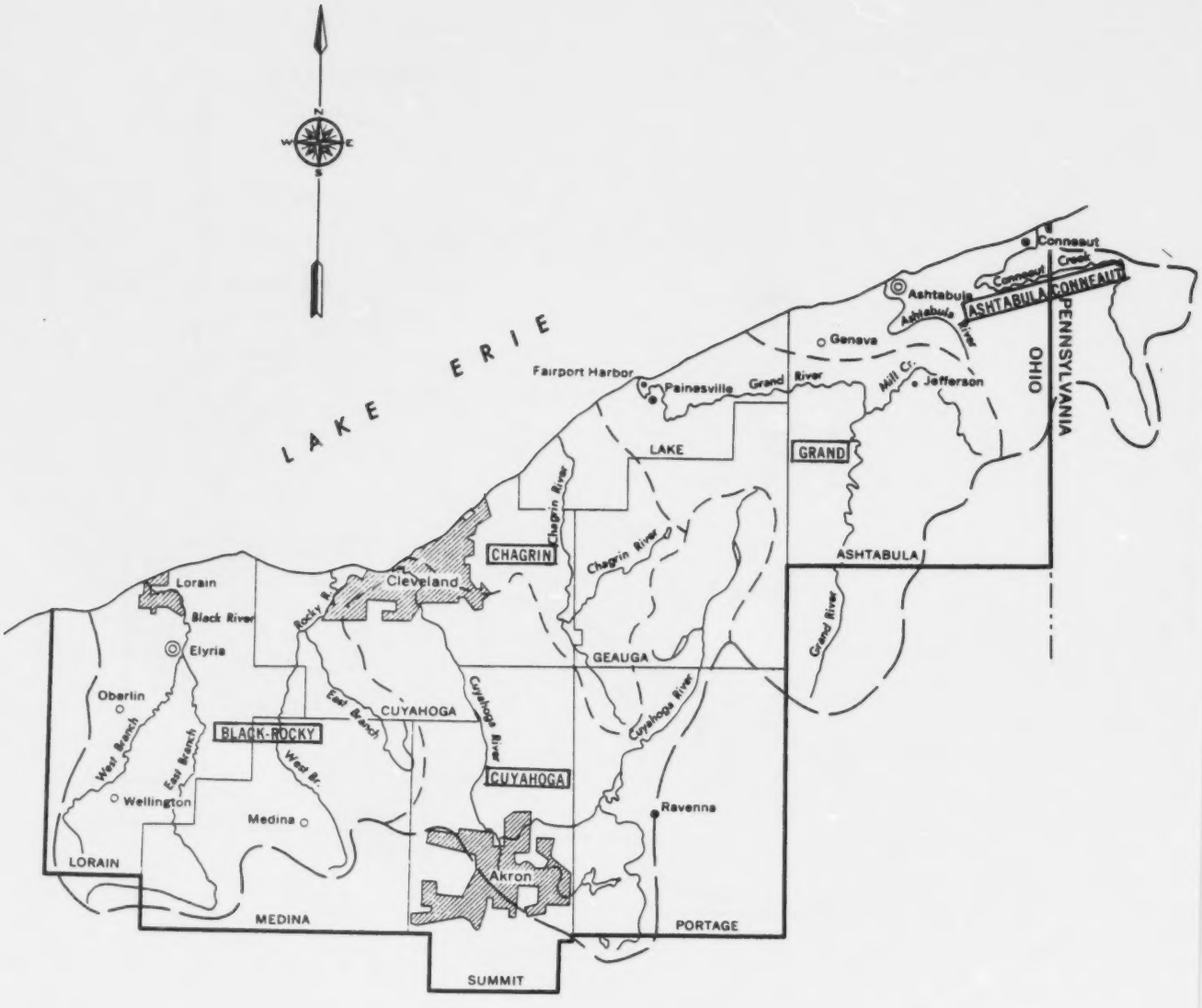


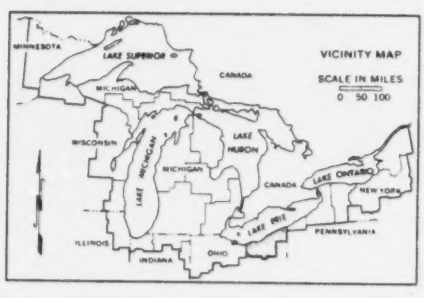
SCALE IN MILES

0 5 10 15 20 25

FIGURE 11

RIVER BASIN GROUP 4.3

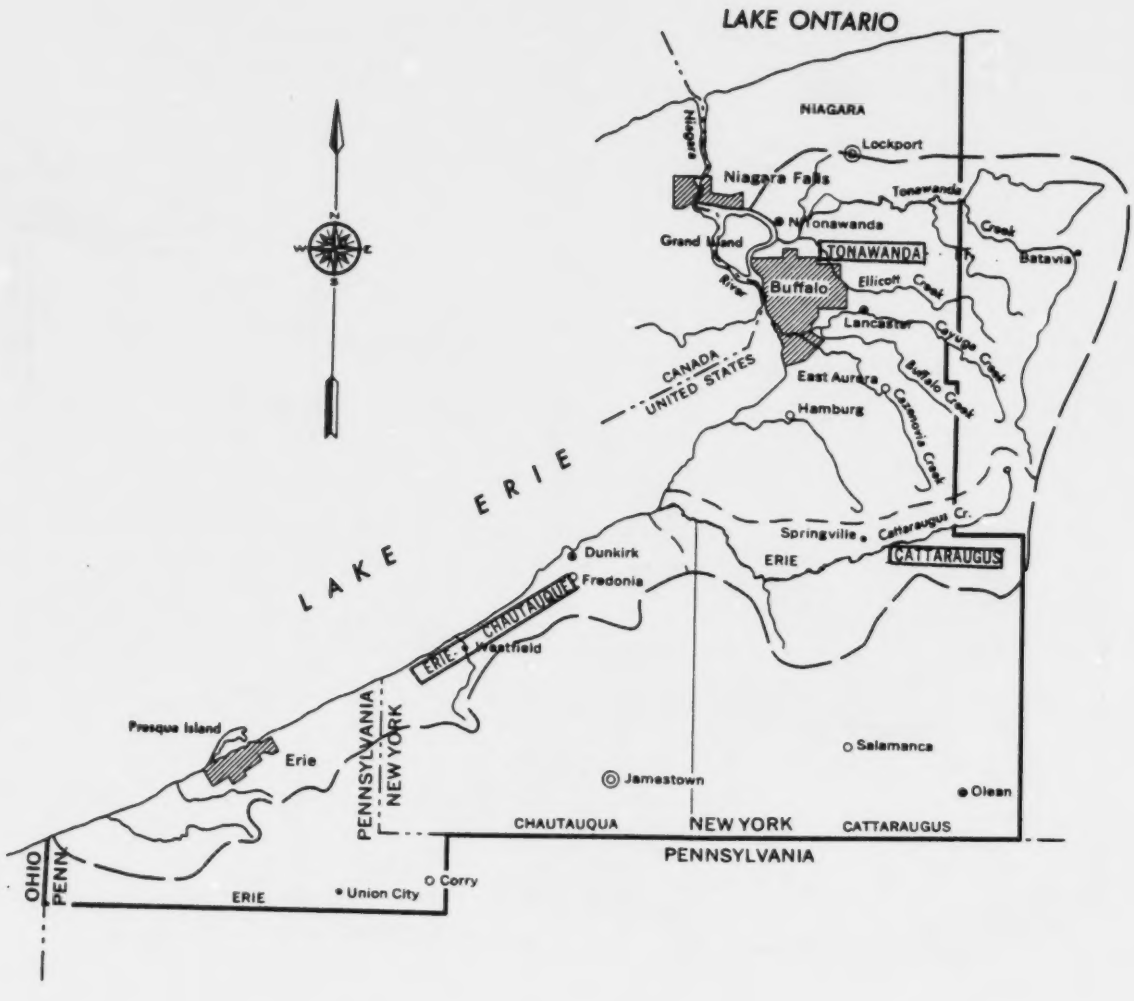




SCALE IN MILES
0 5 10 15

FIGURE 12

RIVER BASIN GROUP 4.4



SCALE IN MILES

0 5 10 15 20

TABLE 5

LAKE ONTARIO
HYDROLOGIC AREA SUMMARY

LAND COVER DATA - PART 1

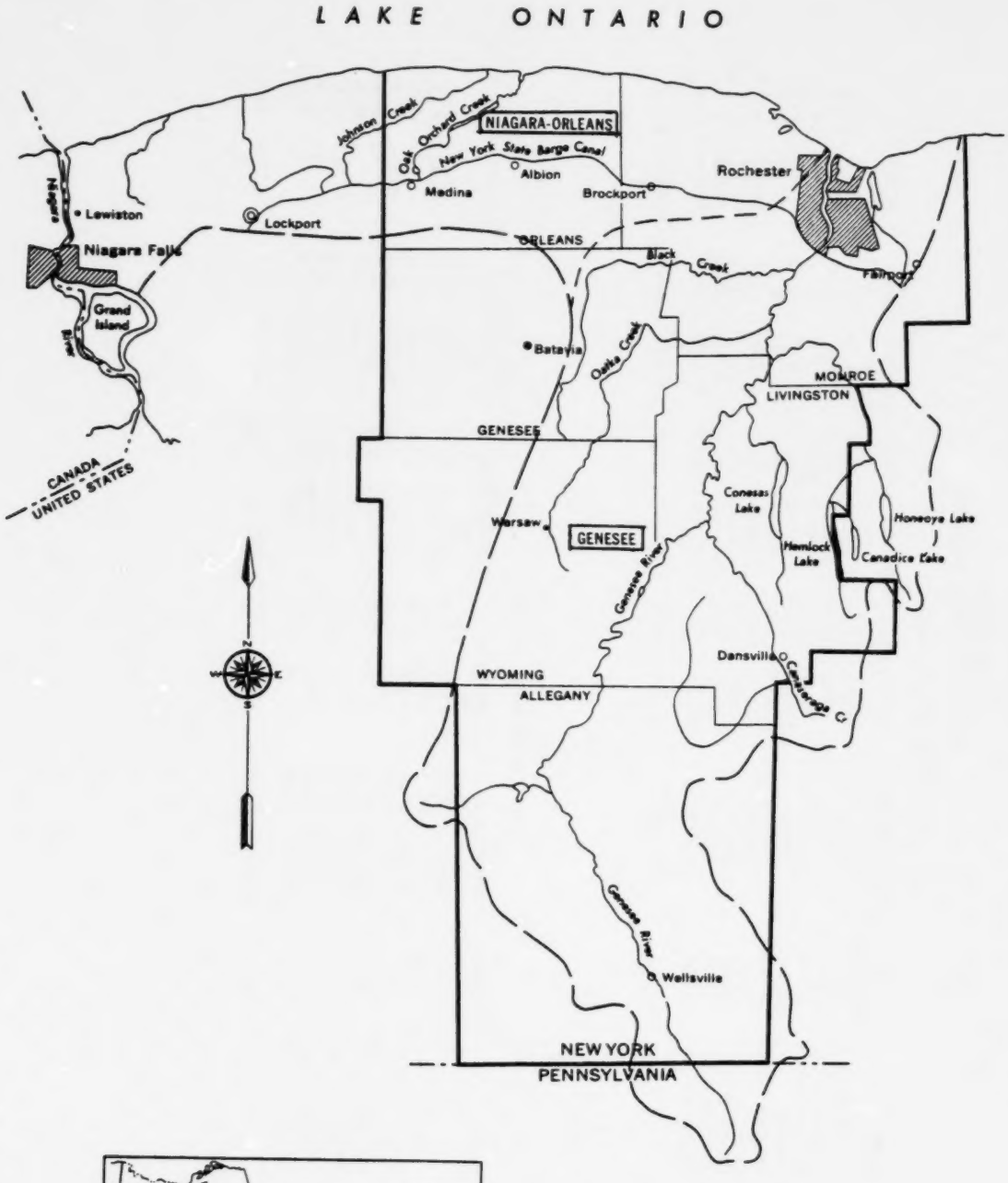
#	NAME	LAND AREA!KM2	INLAND WATER HA		WETLAND HA		FOREST (DECID) HA		FOREST (CON) HA		BRUSHLAND HA	
				%		%		%		%		%
511	NIAGARA-OR C	2690.	2421.		4072.	1.5	126221.	46.9	40174.	14.9	27959.	10.4
512	GENESEE COM	6420.	5136.		3236.	0.5	261460.	40.7	106137.	16.5	75720.	11.8
521	WAYNE-CAYU C	1770.	1947.		3042.	1.7	91990.	52.0	0.	0.0	26129.	14.8
522	OSWEGO	13160.	75012.		15351.	1.2	505188.	38.4	133972.	10.2	160488.	12.2
523	SALMON COM	2730.	5460.		3064.	1.1	79950.	29.3	129814.	47.6	15321.	5.6
531	BLACK	5210.	9378.		5836.	1.1	78521.	15.1	373507.	71.7	14855.	2.9
532	PERCH COM	1260.	24696.		2821.	2.2	31030.	24.6	14104.	11.2	40746.	32.3
533	OSWEGATCHIE	4300.	10750.		8379.	1.9	206400.	48.0	87764.	20.4	46308.	10.8
534	GRASS-RA-SRC	8230.	35389.		22359.	2.7	351731.	42.7	324212.	39.4	59339.	7.2
TOTAL 9		45770.	170189.		68161.	1.5	1732489.	37.9	1209684.	26.4	466865.	10.2

LAND COVER DATA - PART 2

#	NAME	LAND AREA!KM2	GRASSLAND HA	%	BARREN HA	%	PLOWED FIELD HA	%	HIGH DENSITY RESIDENTIAL HA	%	COMMERCIAL HA	%
511	NIAGARA-OR C	2690.	23887.	8.9	271.	0.1	32302.	12.0	13572.	5.0	543.	0.2
512	GENESEE COM	6420.	90605.	14.1	1942.	0.3	84780.	13.2	16179.	2.5	1942.	0.3
521	WAYNE-CAYU C	1770.	19150.	10.8	0.	0.0	22908.	12.9	13781.	7.8	0.	0.0
522	OSWEGO	13160.	191190.	14.5	0.	0.0	219101.	16.6	86524.	6.6	4187.	0.3
523	SALMON COM	2730.	30643.	11.2	0.	0.0	7800.	2.9	6407.	2.3	0.	0.0
531	BLACK	5210.	28650.	5.5	1061.	0.2	8489.	1.6	10080.	1.9	0.	0.0
532	PERCH COM	1260.	24291.	19.3	0.	0.0	10343.	8.2	2664.	2.1	0.	0.0
533	OSWEGATCHIE	4300.	68800.	16.0	441.	0.1	10144.	2.4	1764.	0.4	0.	0.0
534	GRASS-RA-SRC	8230.	49019.	6.0	0.	0.0	12040.	1.5	4300.	0.5	0.	0.0
TOTAL 9		45770.	526233.	11.5	3715.	0.1	407906.	8.9	155272.	3.4	6671.	0.1

FIGURE 13

RIVER BASIN GROUP 5.1



SCALE IN MILES
0 5 10 15

FIGURE 14

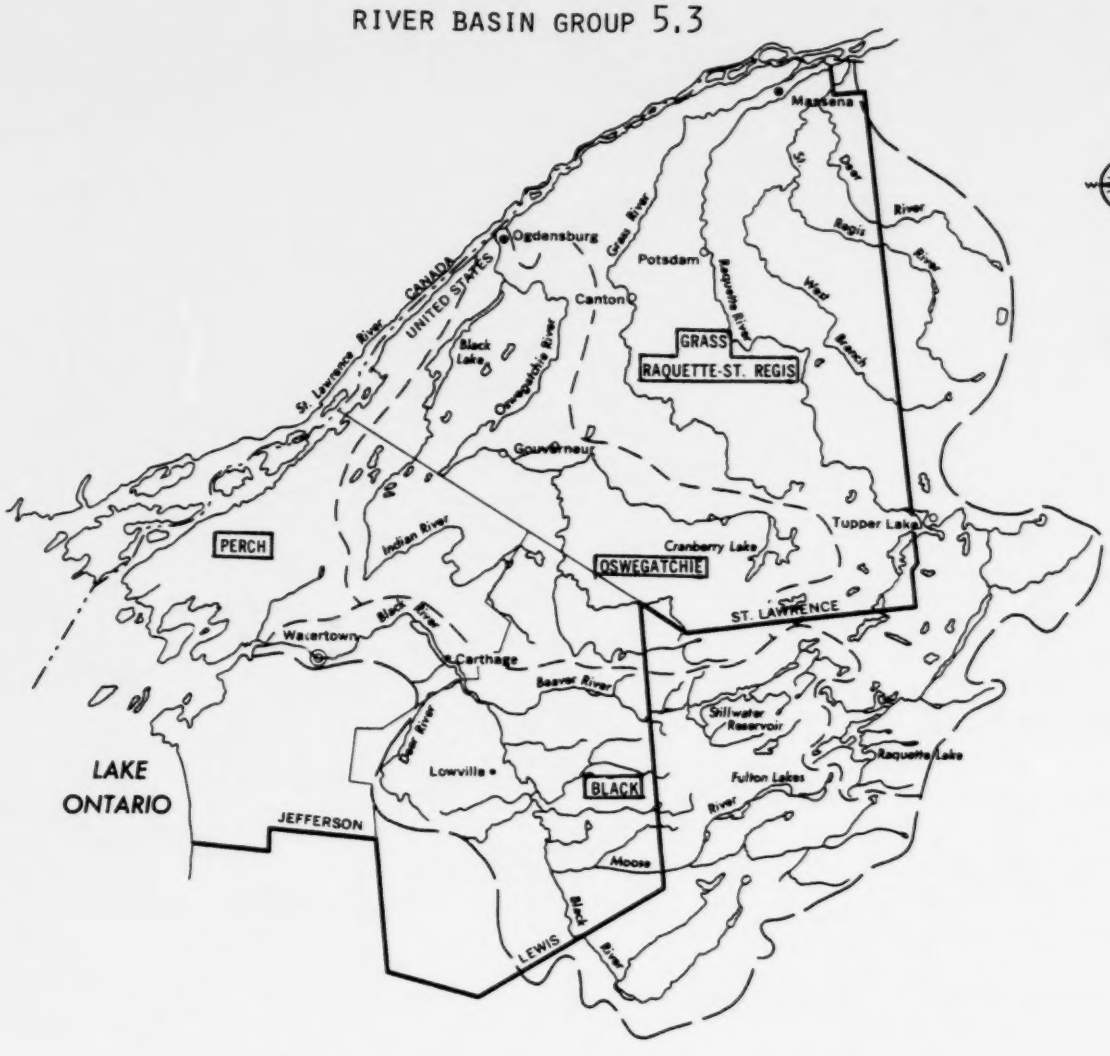
RIVER BASIN GROUP 5.2

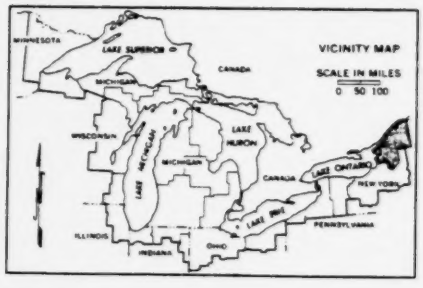
SCALE IN MILES

0 5 10 15 20

FIGURE 15

RIVER BASIN GROUP 5.3





SCALE IN MILES
0 5 10 15 20

FUTURE APPLICATIONS

The General Electric Company, under an extension of their current GLBC contract, is preparing land cover maps based upon their initial analysis of LANDSAT tapes for approximately 50 percent of the U.S. Great Lakes Basin. The maps will be geometrically corrected and prepared at a scale of 1:500,000. They will cover the lower peninsula of Michigan as well as northcentral Indiana and the northwest portion of Ohio. Only two copies of these maps will be produced and no plans have yet been made to mass produce them for general use. One copy will be delivered to EPA in Chicago and the other to GLBC in Ann Arbor.

Another project currently underway will be compiling the land cover data on a county basis, using the classified computer tapes. The results of this GLBC analysis should be available by August of 1978.

Future applications of this data base could include monitoring land cover change, deriving a future breakdown of future crop types, or examing the land cover within particular areas of concern, such as various geographical, political, geological, or topographical features. Since every .45 hectare has been classified, the data base can be arranged and tabulated on any configuration within the U.S. Great Lakes Basin. It would also be very beneficial to map the remaining 50 percent of the Basin and distribute copies to scientists and the public.

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APPENDIX

UNITED STATES
GREAT LAKES BASIN

LAND COVER CLASSIFICATION

by
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FEBRUARY 1978

PREPARED FOR THE

GREAT LAKES BASIN COMMISSION

To be used as a portion of the technical reports of the International Reference Group on GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES of the International Joint Commission--prepared in partial fulfillment of U.S. Environmental Protection Agency Contract No. 68-01-3850 with the Great Lakes Basin Commission.

Findings and conclusions are those of the authors and do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

SUMMARY AND CONCLUSIONS

Digital multispectral satellite data covering the U.S. Great Lakes Basin were processed to create a land cover inventory of the entire watershed. Data analysis, including multispectral signature extraction, data processing, and results verification was performed at the General Electric Image Processing and Analysis Center (IMPAC), Beltsville, Maryland.

The project produced two types of Landsat-derived information products: area measurements and digital tapes. The area measurements, for each of eleven land cover classification categories, were tabulated successively as follows: (1) for the entire U.S. portion of the Great Lakes Drainage Basin, (2) for each of the five Great Lakes basins, (3) for each of 15 large river basins, and (4) for each of 72 sub-basins of smaller rivers. The digital tapes produced contained the original Landsat data and the resultant thematic classification.

Highly interactive computer system techniques were employed to achieve these results in less than four months (mapping of 400,000 hectares per day) and at a remarkably low cost of less than $1.00 per 500 hectares. This is believed to be the largest area mapped through digital image analysis of Landsat data and is certainly one of the most cost-effective large area land cover mapping projects yet performed.

The overall conclusions derived from the results of this study were:

- Interactive classification of Landsat data provides an extremely cost-effective means of performing a regional land cover inventory.
- At least ten useful classes can be achieved with areas of this size.
- While classification accuracy cannot be established without expensive (and extensive) ground truth efforts, classification results may be improved by iteration at any time that new data, satellite or surface truth, is made available.
- Since land use and land cover will change with time, this inventory provides a valuable baseline for future efforts conducted in the entire basin or any part thereof.

SECTION 1

INTRODUCTION

The Great Lakes Basin Land Cover Classification project was performed for The Great Lakes Basin Commission (GLBC) by the Space Division of the General Electric Company. The major information source for the project was digital image data acquired over the basin by the Landsat 1 and Landsat 2 satellites. Supplementary information concerning the area was obtained from USGS topographic maps, atlases and other reference materials, and from verification trips through selected areas of the basin.

The objective of the project was to perform an operational inventory of land cover classes of hydrologic interest over the larger watersheds of the Great Lakes Basin (see Figure 1), and to provide an information source to be used as an economical means of forecasting the effects of existing and new land cover classes on water quality in the Great Lakes.

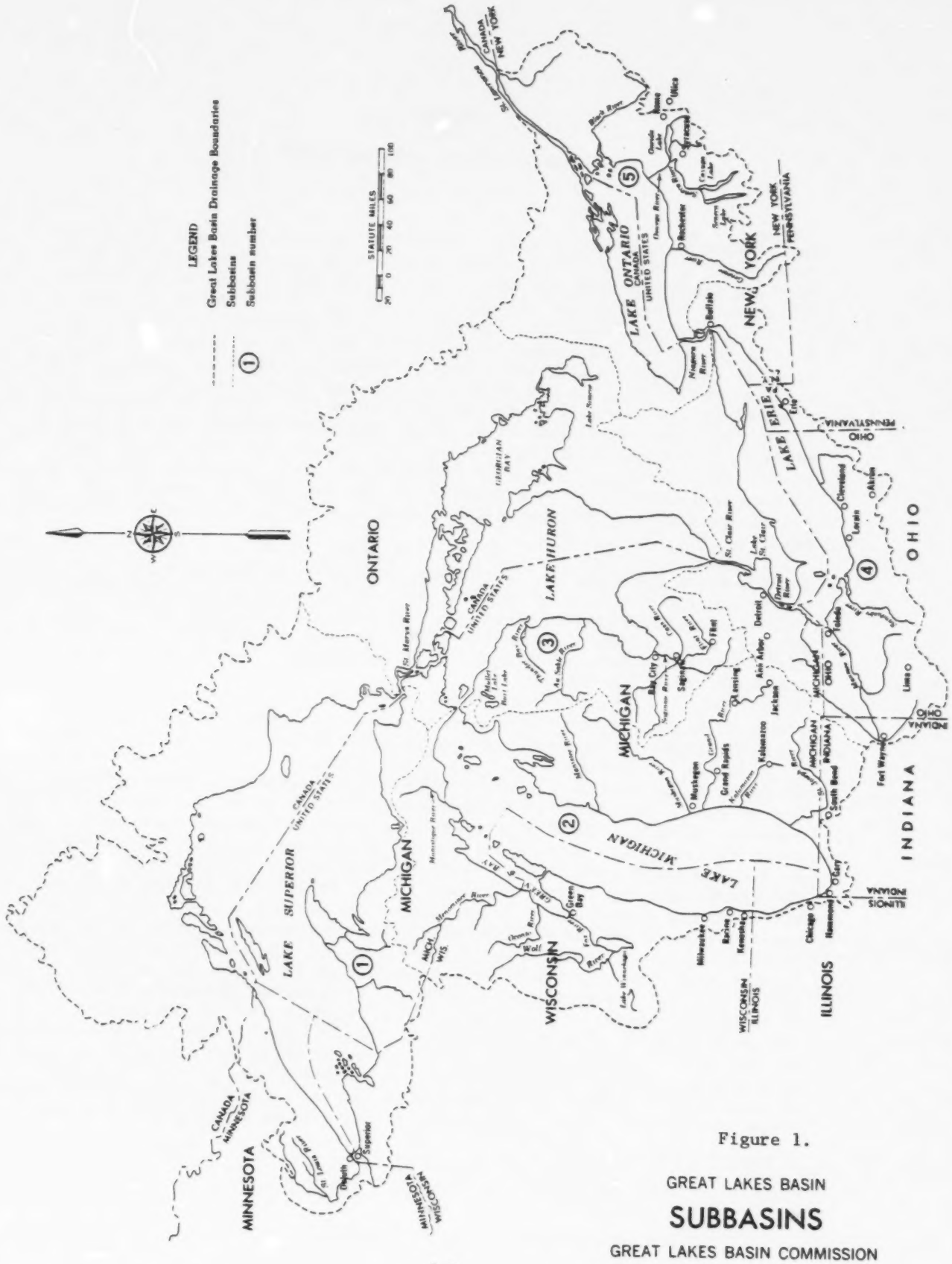

Figure 1.

GREAT LAKES BASIN

SUBBASINS

GREAT LAKES BASIN COMMISSION

SECTION 2

LANDSAT SATELLITES AND DATA*

The primary mission of the Landsat satellite system was to demonstrate the feasibility of multispectral remote sensing from space for practical Earth resource management applications. The overall system requirement was the acquisition of multispectral images, the collection of data from remotely located ground platforms, and the production of photographic and digital data in quantities and formats most helpful to potential users. In addition, it was required that these data be taken in a specific manner: namely, that repetitive observations be made at the same local time; that the images produced by the sensors be overlapping, both in and across the direction of flight; and that the images be correctly located to better than 3.7 km (2.3 miles). Periodic coverage of each area was to occur at least every three weeks. The operating lifespan of the spacecraft and its sensor systems was to be a minimum of one year. Finally, it was necessary to process and distribute all these data to investigators in a useful form and on a timely basis.

To accomplish these goals, the Landsat spacecraft was designed and built by the Space Division of General Electric in Valley Forge, Pennsylvania. This spacecraft, an outgrowth of the Nimbus series of meteorological satellites, was designed to carry two remote sensing systems and a data collection system capable of recording and transmitting data gathered over remote places on the Earth.

The Landsat 1 spacecraft was launched on July 23, 1972, and positioned in the orbit shown in Figure 2. It was followed by Landsat 2, which was placed in operation in January, 1975. For each satellite, the orbit has a nominal altitude of 917 km (570 miles); a 99° orbital inclination, which makes it nearly polar. The orbit is Sun-synchronous, which means that the orbit plane precesses about the Earth at the same angular rate that the Earth moves about the Sun. This feature enables the spacecraft to cross the Equator at the same local time (between 9:30 and 10:00 a.m.) on the sunlit side of the Earth. Each of the two sensing systems, Return Beam Vidicon (RBV) and Multispectral Scanner (MSS), view an area 185 km (115 miles) across. Figure 3 indicates how the requirement for repeat coverage is met. From one orbit to the next, the subsatellite point moves 2875 km (1785 miles) at the Equator as the Earth rotates beneath the spacecraft. The next day, 14 orbits later, it is approximately back to its original location, with orbit 15 displaced westward from orbit 1 by 159 km (99 miles) at the Equator. This continues for 18 days after which orbit 252 falls directly over orbit 1. As indicated in Figure 2, there is a sidelap of 26 km (16 miles) in coverage at the Equator from adjacent orbits on consecutive days. It is important to note that this sidelap increases with increasing latitude, to approximately 57 percent at 60°. Thus, at high latitudes, sidelap coverage is obtained

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* From: Mission to Earth: Landsat Views the World.

on consecutive days over a large portion of an image. In the Great Lakes Region, sidelap is about 45 percent.

The major imaging device aboard Landsat, and the source of data for this project, is the Multispectral Scanner (MSS). The MSS collects data in four spectral bands (0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 micrometers). The four bands (channels) are referred to as bands 4, 5, 6, and 7, respectively.

Figure 4 depicts both the concept of the MSS multi-detector array and the scanning system. The scanning mirror oscillates through an angular displacement of $\pm 2.89^{o}$. For reflected light, the angle of incidence is equal to the angle of reflection, making the scanned swath approximately 11^{o} wide. Six parallel detectors in each of the four bands view the ground simultaneously. The instantaneous field of view on the ground of each detector is 79m square (259 ft. square); thus, each mirror scan covers an along-track distance of approximately 480m (1574 ft.) on the ground.

Each Landsat MSS scene is composed of 2340 scan lines, with each scan line having approximately 3240 resolution elements, called pixels. The radiometric value for each pixel represents an average reflectance over a 79 by 79 meter field of view. Pixels overlap in the long scan (east-west) direction, resulting in an average effective dimension for a single pixel of approximately 57 by 79 meters, or 0.45 hectares. A more detailed description of the Landsat satellite may be found in the Landsat Data Users Handbook.

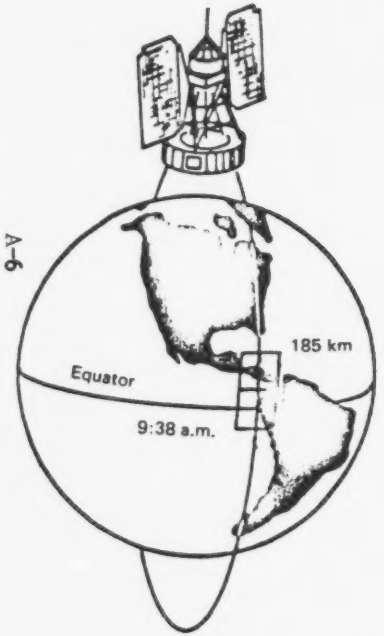

FIGURE 2 —Landsat 1 spacecraft orbit.

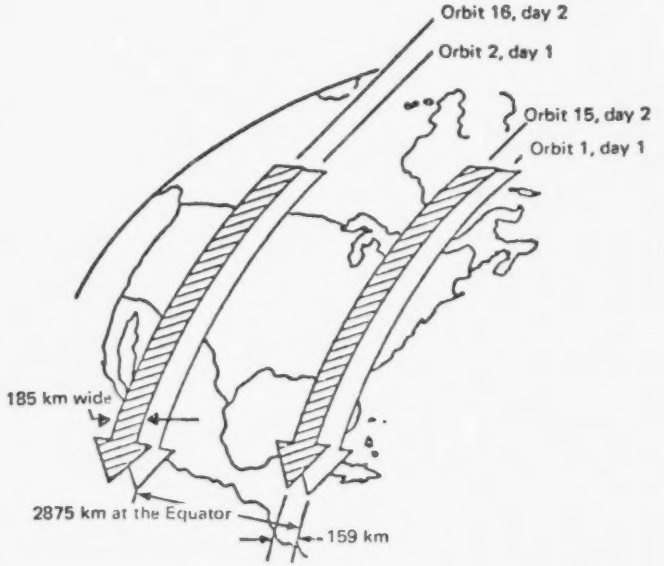

FIGURE 3 —Landsat ground coverage pattern. There are 14 revolutions per day; global coverage is obtained in 18 days.

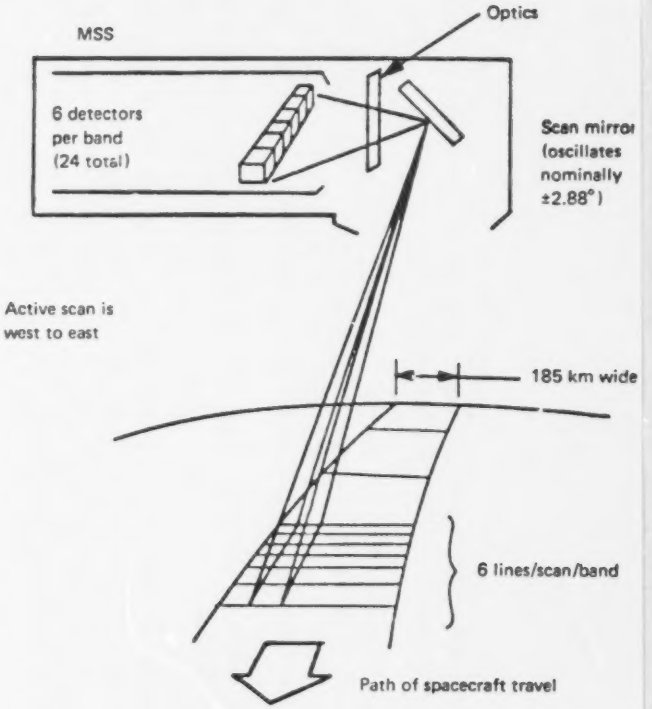

FIGURE 4 —MSS orientation.

SECTION 3

METHODS AND PROCEDURES

3.1 Data Search and Selection

The project data search and selection were performed based on computer listings of all available Landsat 1 and Landsat 2 images containing less than 30% cloud coverage. Listings were acquired from the USGS EROS Data Center. Information included on each listing was image identification number, acquisition date, percent cloud cover, and general quality for each of the four MSS bands. Initial screening of the list was used to make a preliminary selection based on several criteria: (1) low percentage of cloud cover; (2) most recent spring date of acquisition; (3) applicability to the inventory; and (4) availability of groups of images consecutively or closely related in time to assure inter-image compatibility in the classification. All of the scenes appearing to meet these criteria were then visually inspected at the image library of the General Electric Photographic Engineering Laboratory in Beltsville, Maryland, and at the NASA Goddard Space Flight Center (GSFC) Landsat Scene Browse Facility in Greenbelt, Maryland. Visual screening allowed a much more detailed evaluation of image suitability and scenes containing light haze and other unforseeable problems were rejected.

After several iterations, thirty-four exceptionally clear images were selected. These images come from both Landsat 1 and Landsat 2 satellites and were for the most part acquired during spring of 1976 and 1977. Selected images were then ordered in digital (computer compatible tape) form from the EROS Data Center. Table 1 lists the NASA identification numbers and acquisition dates for the selected images. Figure 5 shows the location of the images with respect to the Great Lakes Basin.

3.2 Ground Truth

"Ground truth" in satellite related work is defined as any combination of information about ground observations, measurements from topographic and other maps, and information extracted from aerial photographs. Ground truth data aids the analyst in identifying land cover types and in verifying the classification. Information concerning the land cover in the Great Lakes Basin came from all these sources. It was not evaluated at a very fine or "individual field" level as that would have been impractical over an area the size of the basin or at the least, extremely expensive. A set of USGS topographic maps covering the basin was used as the primary information source. While such maps are not completely up-to-date nor completely accurate, they are an excellent tool for locating or verifying trends in land cover. Based upon these maps and an interpretation of the images, an initial classification was performed, then verified and/or revised based upon other available information. Several of the additional sources utilized were:

1. Publications of aerial photographs of the basin;

2. Conferences with persons native to certain areas in the basin;

3. Automobile trips through the area, which allowed investigation of several areas on the ground;

4. Phone conversations with local forest service officials.

SCENE ID	LOCATION	PATH-ROW	DATE
2850-14465	Watertown	16-29	21 May 77
2850-14471	Utica	16-30	21 May 77
5770-14083	Rochester	17-30	28 May 77
5770-14085	Binghamton	17-31	28 May 77
2474-15124	Buffalo	18-30	10 May 76
2474-15130	Allegheny	18-31	10 May 76
2169-15242	Erie	19-31	10 July 75
2836-15112	Cleveland	20-31	7 May 77
2836-15114	Canton	20-32	7 May 77
2855-15154	Port Huron	21-30	26 May 77
2855-15160	Detroit	21-31	26 May 77
2855-15163	Lima	21-32	26 May 77
2856-15205	Alpena	22-29	27 May 77
2856-15212	Flint	22-30	27 May 77
2856-15214	Jackson	22-31	27 May 77
2856-15221	Ft. Wayne	22-32	27 May 77
2497-15400	Sault St. Marie	23-28	2 June 76
2497-15402	Cadillac	23-29	2 June 76
1321-15584	Muskegon	23-30	9 June 73
2839-15282	South Bend	23-31	10 May 77
2840-15325	Alger	24-28	11 May 77
2498-15460	Travers City	24-29	3 June 76
2498-15465	Chicago	24-31	3 June 76
2499-15512	Escanaba	25-28	4 June 76
5385-15264	Green Bay	25-29	8 May 76
5385-15271	Milwaukee	25-30	8 May 76
5386-15313	Keweenaw	26-27	9 May 76
5386-15320	Land-O-Lakes	26-28	9 May 76
5386-15322	Lake Winnebago	26-29	9 May 76
5387-15371	Isle Royale	27-27	10 May 76
5387-15374	Ashland	27-28	10 May 76
5388-15425	Two Harbors	28-27	11 May 76
5388-15432	Duluth	28-28	11 May 76
2827-16015	Duluth	29-28	28 April 77

Table 1. Landsat Scenes Used in Inventory

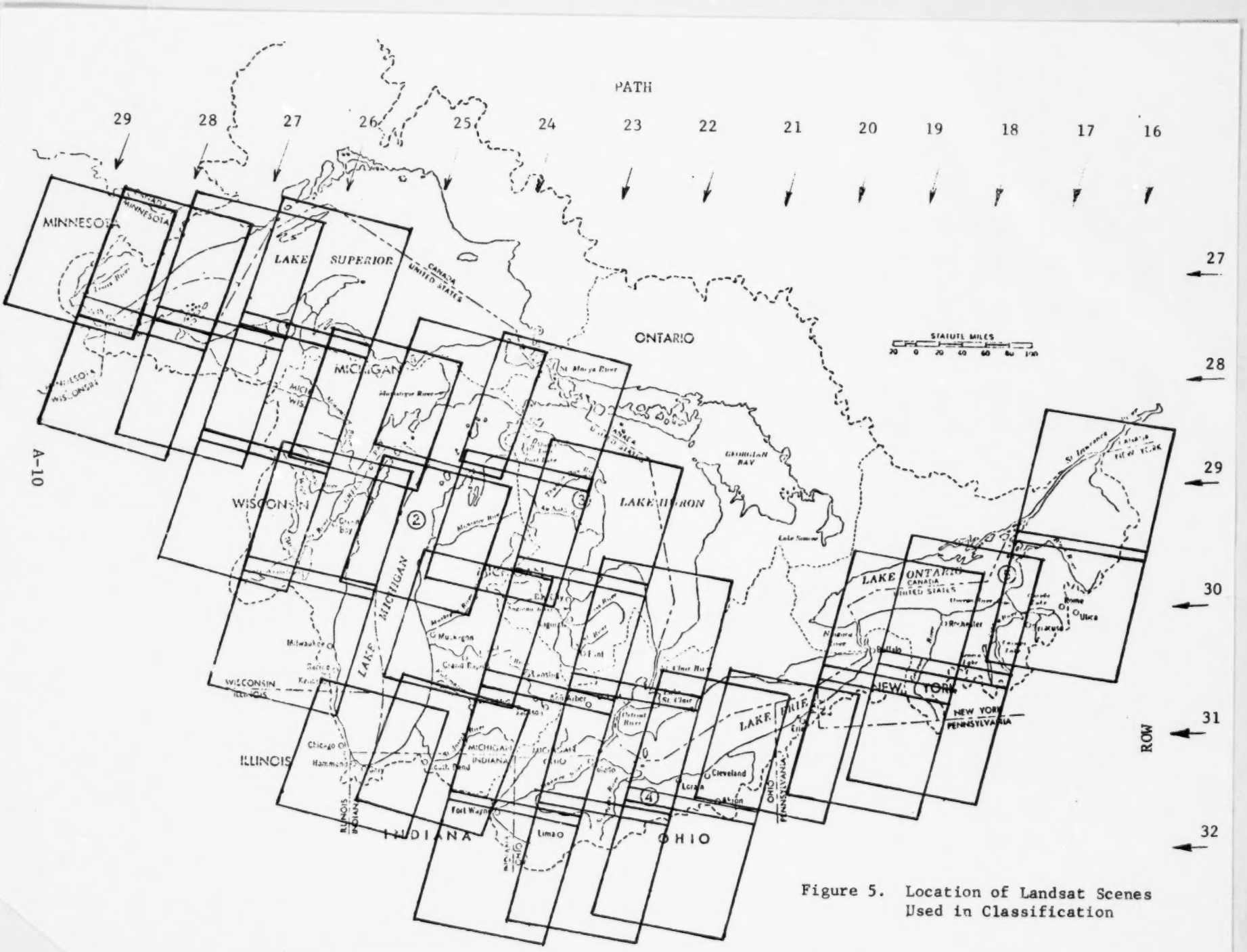

Figure 5. Location of Landsat Scenes Used in Classification

3.3 Processing of Data

3.3.1 Digitization of Sub-basins

To produce classified theme area measurements by sub-basin, spatial zones approximating the sub-basins were digitized in the form of polygons. Each polygon was defined by sets of vertices in an arbitrary x-y coordinate system and was traced from hydrologic maps supplied by the GLBC. The curved sub-basin boundaries were then closely approximated by a series of line segments.

Before the sub-basin boundaries could be used with Landsat data, it was necessary to transform the digitized polygons and Landsat images to a common coordinate system. It would seem logical to transform Landsat images to a map based coordinate system and have all data geographically referenced. Computationally, however, it is far more efficient to transform the relatively few points defining the polygons to the Landsat image, than it would be to transform the large number of Landsat scene picture elements (7×10^6) to another coordinate system.

In order to convert the polygon vertices from their x-y coordinates to the Landsat digital image coordinates based on pixels (columns) and scan lines (rows), it was necessary to locate three or more ground control points for each scene. Points in the Landsat system were located using an interactive image display and electronic cursor, while the corresponding x-y points were scaled from the hydrologic maps. The actual transformation of points was a linear transformation determined by applying a least squares fit technique to the control points.

Due to the large size of watersheds, the fact that they were situated randomly on Landsat scenes and the occurrence of clouds in areas covered by sidelap, most of the watersheds were divided into two or more sections. Usually, more than one Landsat scene was required to cover each watershed, and a watershed section was needed from each of the scenes. After processing of the data, area measurements for these sections were summed to reflect full watersheds. While efforts were made to keep this sectioning to a minimum, approximately one hundred and sixty polygons were required to process seventy-two watersheds.

To avoid the problem of actually following an often ragged Great Lake shoreline when the shore bounds a sub-basin, water classification was used to accurately define the boundary. The sub-basin polygon was extended well into its associated lake. Another polygon, including all Great Lake waters and extending slightly onto the shore was used to classify Great Lake waters.

The true area of the sub-basin was then the sub-basin polygon minus the area of Great Lake waters included in that polygon. This is graphically shown in Figure 6.

3.3.2 Interactive Analysis

The digital analysis of Landsat data was performed using the General Electric Interactive Multispectral Image Analysis System, IMAGE 100 (Figure 7). The basic system consists of the following:

1. Input and output devices - two magnetic tape drives, input scanner unit, line printer and DICOMED digital image film recorder.

2. Image Analyzer Console (IAC) involving special purpose hardware for interactive image analysis. The IAC contains a refresh memory, a color TV display, control buttons and processing circuitry.

3. A minicomputer used for process control during interactive image analyses, and for bulk processing of digital data for entire Landsat scenes.

4. Two real-time display subsystems - the color TV display in the IAC, and the graphics display terminal.

The IMAGE 100 operates directly from computer compatible tapes (CCTs) that contain preprocessed multispectral digital data acquired by Landsat. Input data is read directly from 9-track CCTs into the IMAGE 100 refresh memory. From there, preprocessing, multispectral analysis and theme synthesis for Landsat subscenes (512 x 512 pixels) is performed interactively in an operator-machine mode using the Image Analyzer Console and the process control minicomputer.

Correct categorization of remotely sensed digital data depends heavily on the analyst's knowledge of the area being investigated. The first step was a careful examination of maps and photographs, plus a review of all ancillary information collected. Based on this examination, training sites are selected from each Landsat scene. Training sites are small portions (samples) of the Landsat scene that give fair representation of the entire scene. Attempts were made to include in the training sites all of the land cover types characteristic to a given scene. Two or more sites were selected out of each Landsat scene. The multispectral digital data for each of these sites were extracted from the CCT and stored in the IMAGE 100 refresh memory so as to produce a stored image of a composite training site. This stored image was then displayed on the IMAGE 100 color TV monitor to aid in the spectral signature acquisition process.

Once the training sites for a given Landsat scene were selected, the next step was to extract spectral signatures. This was performed using a data space partitioning technique. This is a highly interactive supervised classification method where decision planes are sequentially inserted into the data space. It allows the analyst to divide the space into volumes corresponding to various land cover types. The IMAGE 100 color display shows the thematic mapping corresponding to each volume superimposed on the test site. The results are then interpreted and evaluated against the

existing ground truth information. Adjustments are made where needed until satisfactory spectral signatures are determined.

3.3.3 Bulk Data Processing

After satisfactorily extracting land cover spectral signatures through interactive analysis on the IMAGE 100, processing was switched to a batch or bulk processing mode to handle the huge amount of data involved: 3×10^7 picture element intensity values per scene or 1.0×10^9 values in the entire data set. This involved the processing of 17 miles of magnetic tape at 1800 bits per inch.

The bulk processor, or entire scene classification program, was applied to each of the Landsat scenes involved. Program input consisted of the Landsat digital scene, the polygons associated with that scene and the multispectral signatures of the land cover classes in that scene.

The output of the bulk processor is in two forms. First, a so-called pseudo CCT or classified tape in the Landsat tape format is generated. In this tape, the digital values for MSS bands 4, 5 and 7 have been replaced by respectively inserting color intensities for blue, green and red. These color intensities create a map showing the classification of each pixel. The pseudo CCTs serve as a digital record of the classification and as the means by which to verify the classification.

The second form of output is a table of area summaries reflecting the number of hectares of each thematic class within each of the sub-basin polygons. Table 2 is an example of the summations performed for the Detroit area scene (2855-15160). Figure 6 is a graphic display of the polygons associated with the same scene.

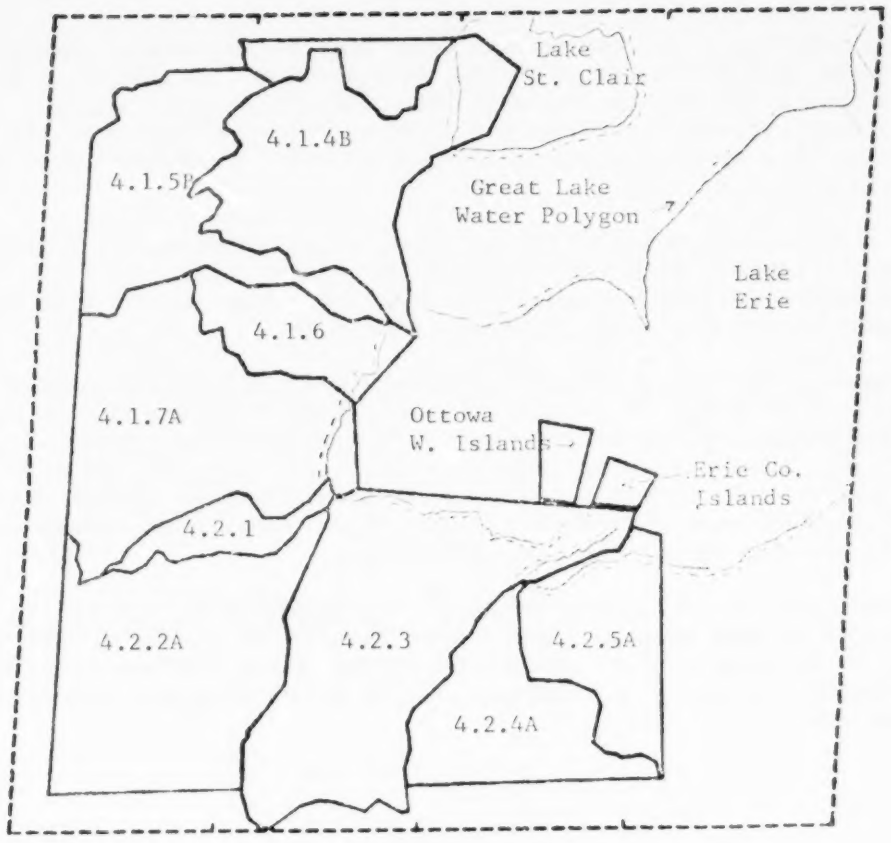

Figure 6. Sub-basin Polygons for Scene 2855-15160

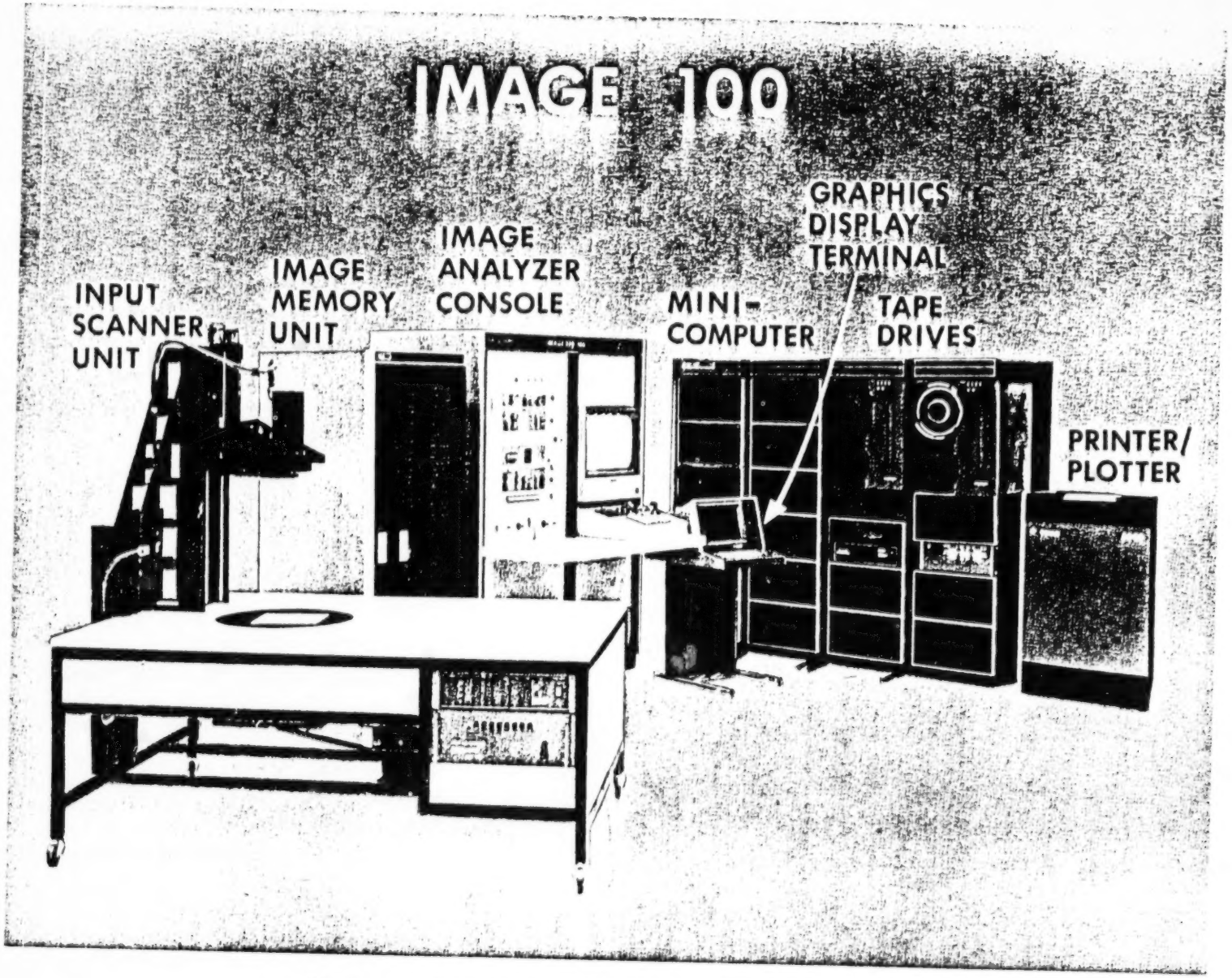

Figure 7. General Electric Interactive Multispectral Image Analysis System, IMAGE 100

***** GREAT LAKES LAND COVER CLASSIFICATION LANDSAT SCENE ID 2855-15160 *****

THEME AREA SUMMARY TABLE
IN
HECTARES

AREA NAME	TOTAL AREA	GL WATER	WATER	WETLAND	FOREST	GRASSLAND	AGRICULTUR	BARREN	RESIDE PT1
4.1.3 B	44789.		1745.	370.	3583.	1294.	2732.	63.	14007.
4.1.4	222535.	27436.	1167.	613.	20381.	7793.	12602.	273.	58999.
4.1.5 B	171903.	13.	5319.	2920.	41603.	17146.	25604.	117.	3933.
4.1.6	79283.	7181.	107.	979.	8615.	3537.	26355.	72.	36.
4.1.7 A	268908.	11805.	433.	2465.	21021.	27648.	132296.	323.	
4.2.2 A	267703.	1.	2553.	1881.	15577.	19405.	157696.	100.	133.
4.2.3	327654.	45671.	2959.	2997.	20273.	14209.	160498.	517.	
4.2.4 A	126076.	642.	596.	1320.	12937.	12477.	70131.	813.	
4.2.5 A	114508.	12543.	499.	3353.	11384.	7844.	49684.	522.	
4.2.1	42648.	914.	222.	212.	3488.	2679.	16765.	34.	
ERIE ISLE	10301.	9145.		62.	626.	28.	75.	3.	
DITTOW ISLE	17002.	15718.		113.	516.	95.	145.		
IMAGE	3432210.	876273.	26302.	37265.	285226.	217968.	1115357.	4642.	94937.

TABLE 2. COMPUTER PRINT FOR CLASSIFIED SCENE 2855-15160

***** GREAT LAKES LAND COVER CLASSIFICATION LANDSAT SCENE ID 2855-15160 *****

THEME AREA SUMMARY TABLE
IN
HECTARES

2 OF 2

AREA NAME	TOTAL AREA	RESIDE PT2	COMMERCIAL	CLD COVER	BRUSH	RES PT3
4.1.3 B	44788.	8477.	4631.	1.	7883.	
4.1.4	222535.	19747.	35189.		35723.	2612.
4.1.5 B	171903.	822.	2190.		55345.	16891.
4.1.6	79283.	23.	97.		19869.	12410.
4.1.7 A	268908.	201.	1317.		47867.	23532.
4.2.2 A	267703.	853.	2877.		43775.	22851.
4.2.3	327654.	171.	863.		49641.	29847.
4.2.4 A	126076.		399.	13.	17869.	8845.
4.2.5 A	114508.		789.	9.	16636.	11208.
4.2.1	42648.	1024.	2304.		9438.	5568.
ERIE ISLE	10301.				295.	67.
OTTOW ISLE	17002.				364.	52.
IMAGE	3422210.	35312.	57893.	62.	488210.	189142.

TABLE 2. (continued)

SECTION 4

RESULTS

4.1 Classification

Classification was undertaken with the objective of extracting as many meaningful classes as possible, which were sufficiently global to be applied to all thirty-four images. A total of eleven classes were finally extracted.

Two of the classes (evergreen forest and extractive), while not applicable throughout the basin, were of sufficient importance to be extracted whenever possible. In scenes where they were not extractable, these classes were combined with mixed forest and barren, respectively.

Miscellaneous land cover classes found only in local geographic areas were combined with the best suited of the eleven global classes. For example, harvested forest, which was apparent only in Minnesota was combined with the brushland class.

Often some of the eleven classes were composites of two or more types of land cover. This was particularly the case for the residential class. Residential areas are typically spanned by a wide range of land cover, depending on varying population densities and length of time since development. They do not exhibit unique spectral characteristics. For some of the scenes, up to three local residential classes were extracted and then combined to form the global residential class.

4.2 Class Definitions and Comments

Water - A geographic distinction was made between water within the Great Lakes themselves and the water within inland lakes and rivers. Area tabulations pertain to inland waters only and thus reflect land cover area in the sub-basins.

Wetlands - Areas classified as wetland include those where land cover is a mixture of water and vegetation, and those areas inundated with water often enough to restrict vegetation to marsh species. Forested wetlands with nearly complete canopy closure are not included.

Evergreen Forest - This class was extracted when it covered large enough contiguous areas to create the predominant land cover and thus display, spectrally, a sharp contrast to deciduous forest. The class was apparent only in the northernmost portions of the basin and was particularly good around Lake Superior and in the Adirondack Mountains of New York. Where both types of forest were present, the evergreens seemed concentrated spatially in the poorly drained low lying areas, sometimes appearing as rings around the more well-drained hills.

Mixed Forest - In the southern portions of the basin where forest is predominantly deciduous, and in portions where the percentage of land covered by forest is small, this class represents total forest. In northern areas where evergreens could be classified, the mixed forest class represents only the deciduous component of total forest.

Brushland - This is a class comprised of very low density forest, harvested forest, scrub, and neglected farms. Those picture elements covering a mixture of barren and vegetated areas are also usually included in this class.

Grassland - This class represents most areas other than forest which are completely and densely covered with lush vegetation. Its main component was pastureland, making it a major class in Wisconsin and New York. Also included were open parks, golf courses, and any grass crops characterized by full ground coverage at the image acquisition date.

Plowed Field - The plowed field class is defined to contain any areas characterized by bare, recently cultivated soil at the date of image acquisition or which contained crops with a small percent of ground coverage. Image dates were primarily in May, so a shortcoming of the class is that any crops such as winter wheat which had achieved full ground coverage are ommitted. In unpopulated areas, total agriculture will be the sum of recently plowed fields and grassland classes.

High Density Residential - This class is especially difficult to extract due to the wide range of land cover involved. For most of the images, a minimum of two spectral signatures were required, onr for recently developed suburbs with minimal vegetation, and one for older suburbs containing trees, higher housing densities, and weathered rooftops. The class is quite good near the large population centers of the basin and in small city centers. In some of the more remote areas containing only small villages, no high density residential class was extracted.

Extractive - This class was used only in the Lake Superior region where significant mining activity was being carried out. It includes both extractive areas and mine tailings.

Barren - This class includes any areas of high reflectance devoid of vegetation, such as sand, beaches and areas of recent construction. Outside of the Lake Superior basin, it also includes extractive areas.

Burn Area - One unexpected result of the project was the mapping of the Seney fire burn scar. The fire occurred in Michigan in the fall of 1976. Image #2870-15325, acquired in May of the following year, clearly showed the large area that had been consumed by fire.

Clouds - When they appeared, clouds and cloud shadows were classified. Most areas of the basin were covered by two images because of image side lap and it was possible to work around nearly all the cloud affected areas of the image set. The only place where cloud cover significantly interferred with classification was in a small area in the vicinity of Erie, Pennsylvania.

Commercial - This class is comprised of areas within cities which were totally devoid of vegetation and areas which have been discolored by industrial practices.

4.3 Accuracy Estimates

To achieve statistically significant accuracy measurements or estimates involves at a minimum, randomly selecting many sample areas and comparing the land cover classification results with other information assumed to be totally accurate. A typical approach would be to randomly select several sample areas to be used in verifying the classification. Ground truth information in the sample areas would be acquired through photointerpretation of low altitude aerial photographs. The required number and size of these areas would be determined by the level of confidence desired in the accuracy estimates.

Such an effort is well beyond the scope and intent of this inventory, and a qualitative accuracy will be given instead.

Classification accuracies depend on many factors, perhaps the most important being the definition of the classes. In this inventory, class definitions lean more toward spectral characteristics of land cover than on existing and sometimes inappropriate land use definitions. While there is some objection to redefining classes in this manner, it may be a way of obtaining maximum information from Landsat data. Also of great importance is the spatial distribution of the classes. If classes occur in large contiguous blocks, as water and forest often do, very high accuracies can be achieved. In general, accuracies decrease as contiguous area sizes decrease. In the extreme limit, when the area contiguously classified is only a few pixels, the likelihood of these pixels being classified correctly is quite poor unless it happens to be in a class that exhibits spectral characteristics that are very unique.

Another very important factor is the geographic extent of the area to be classified. How well a classification is performed is as much dependent on the spectral characteristics of land cover types from which a class must be separated as it is dependent on the spectral characteristics of that class. Local or small area classifications sometimes form clusters or concentrations in multidimensional data space, but global (entire scene) data space distributions are generally more uniform. Except for classes like water and forest, they rarely fall into useful clusters. It is much easier to classify small test areas than it is to classify entire Landsat scenes. Similarly, classifying multiple scene areas represents still another level of difficulty. In multiple scene analysis, one must also contend with radiometric differences between images resulting from atmospheric and sun angle effects and with changes in land cover of a class between dates.

The percentages of expected accuracy are listed in Table 3 and represent intuitive estimates based upon examinations of the classified images and previous experience. They should display the relative confidence one can place on each of the classes.

Class	Estimated Areal Accuracy
Water	75-90%
Wetland	50-75%
Evergreen Forest	85-90%
Mixed Forest	75-90%
Brushland	50-60%
Grassland	65-75%
Plowed Field	70-90%
High Density Residential	50-70%
Commercial	65-80%
Barren	40-60%
Extractive	65-75%

Table 3. Estimated Accuracy

Hopefully, the ultimate users of these data will use and evaluate them on a macro-scale rather than a micro-scale basis. Too often, users weigh individual Landsat picture elements, which may represent a mixture of ground cover types, too seriously. Those who accept the fact that their backyard may be classified as brushland instead of a residential area because of similar land cover mixtures, will make better use of the data than those who dwell on the classification error. Likewise, applications that utilize wide area figures and trends rather than micro-scale mapping will be more successful. Clearly, higher mapping accuracies can be obtained by expending large efforts on small test areas, but it is more likely that Landsat achieves its full potential in the type of wide area classification performed in this study.

4.4 Classified Magnetic Tapes

One 1600 bits per inch magnetic tape was created for each Landsat scene. They serve as a permanent record of the classification and may be used in the future to create map products. Data are in the standard Landsat format, but the original data from MSS bands 4, 5, and 7 have been replaced with encoded colors for each of the thematic classes. Data from MSS 6 have been left intact. The color code used is listed in Table 4.

CLASS	COLOR	MSS4	MSS5	MSS7
INLAND WATER	BLUE	127	0	0
GREAT LAKE WATER	BLUE	127	0	1
WETLAND	CYAN	127	127	0
MIXED FOREST	GREEN	0	84	0
EVERGREEN FOREST	GREEN	0	15	0
BRUSHLAND	TAN	79	103	53
GRASSLAND (INCLUDING PASTURE, GOLF COURSES)	LIGHT GREEN	24	127	12
BARREN	WHITE	127	127	63
EXTRACTIVE	WHITE	126	127	63
AGRICULTURE	ORANGE	0	72	63
AGRICULTURE (PT 2) (DARK OR DAMP SOIL)	ORANGE	1	72	63
RESIDENTIAL (PT 1)	YELLOW	0	127	63
RESIDENTIAL (PT 2)	YELLOW	1	127	63
COMMERCIAL/INDUSTRIAL	RED	0	0	63
BURN SCAR	BROWN	0	55	33
OBSCURED BY CLOUDS	BLACK	0	0	0

Table 4. Landsat CCT Format Classified Tape Color Code